NASA Long Range Technology Goals

Volume I

Task 2 Report

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FOREWORD

This document is part of the Final Report of an effort performed under contract NASW-3864, titled "NASA Long Range Technology Goals."

The objectives of the effort were:

- To identify technologies whose development falls within NASA's capability and purview, and which have high potential for leapfrog advances in the national industrial posture in the 2005-2010 era.
- To define which of these technologies can also enable major advances in the national space program.
- To assess mechanisms of interaction between NASA and industry constituencies for realizing the leapfrog technologies.

This Volume summarizes the methodology used and the findings of the study.

Volumes II through V detail the methodology and the findings.

OUTLINE OF VOLUMES

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EXECUTIVE SUMMARY

In the past decade, the U.S. experienced a slowdown in growth of productivity and an erosion of its international posture of industrial leadership. In this study, ECOsystems International and Arthur D. Little examined NASA's potential to redress these trends by stimulating long-term, leapfrog technology advances realizable in the 2005-2010 era.

BACKGROUND

The following considerations and hypotheses lie at the root of the study:

- That the nation's eroding posture with respect to productivity growth and industrial leadership, resulting from diverse factors, could be remedied and even turned around through application of innovative industrial technologies.

- That a measure of coordinated focus by government and industry may be needed to bring these new technologies to fruition. The County Agent system in which government acts as catalyst for bringing new technology to farmers, is an example. Begun in 1884, it has fostered the highest level of agricultural productivity in the world.

- That many aspects of the advanced technologies NASA will need to enable imaginative future space programs may be common to the technologies needed to revitalize U.S. industrial productivity.

- That NASA may be in a particularly strong position to assume a significant role in focusing national technological developments. In harnessing U.S. industrial resources for the nation's space program, NASA has built up unique scientific and technical know-how and management capability.

METHODOLOGY

We examined these considerations by analyzing 20 industrial subsectors and 45 subdivisions of the economy to assess the degree to which long-term technology improvements could mitigate current and forecasted slowdowns. We assessed the technological needs of these industries and identified a set of technologies common to most of them. We also analyzed technology's role in advancing noneconomic aspirations, such as health and security. In parallel, we identified key, long-term technologies that NASA itself will require to enable advanced space missions; and we assessed their commonality with those needed by industry.

CONCLUSIONS

The study's principal conclusions are:

- The U.S. is still ahead of other developed nations in generating GNP, in overall productivity, and in satisfying noneconomic aspirations, but the U.S. lead is waning. As things stand, the lead could be dissipated by about the turn of the century.

- Aging inflexible plants, inefficiencies of training and education systems, constraining government regulations, and a transition from manufacturing toward service industries are among the factors causing lowered productivity.

- Technology plays a dominant role in driving productivity gains. More than half of the productivity gains in the "boom" period 1948-66 for example, resulted from increased "know-how." Foreign economies have also increased their productivity through technology. Capitalizing to a large extent on technologies imported from the U.S., they avoided the expense and lead time needed to build their own technology bases, thus accelerating their rate of growth above that of the U.S.

- Historically, in peacetime, the U.S. has placed major reliance upon industry to develop technology. Industrial R&D, conducted within hundreds of individual firms, is by its nature industry-specific, because of each sponsor's need to preserve his competitive status. Industrial R&D operates within short-term horizons, necessitated by pressures for rapid return-on-investment. These constraints make it difficult for industry to engage in basic research with long term fruition, even though the potential payoff may be high.

  In recent years, foreign competition has pointed up limitations of relying solely on industry for realizing long-term technology objectives. Japan, for example, has employed innovative mechanisms for government-industry interactions in basic, long-term, high payoff technologies such as advanced materials, robotics, artificial intelligence. Similar mechanisms, properly structured, could be effective in the U.S.

- Coordinated government-industry programs need to be structured with care to maintain incentive and competitiveness, and at the same time overcome constraints caused by industry's limited horizon and fragmentation. Such programs should be aimed primarily at technologies that are basic, long-term and common to the requirements of broad classes of industries. Our study identified **ten** such "pervasive" technology goals whose accelerated development would bring about major gains in national productivity and competitiveness.

1. **Advanced Materials**--with strength-to-weight ratios not heretofore available, or that provide more economical substitutes for available materials. Examples are hyper-strength, low-weight plastics and ceramics.

2. **Custom Multi-Property Materials**--that can be flexibly designed and synthesized at the molecular level to achieve characteristics tailored to fit specific applications. An example is engine blocks that require no machining and exhibit varying, requisite properties, such as hardness and heat resistance in combustion zones and vibration resilience in mounting areas.

3. **Mobile Energy Storage Devices**--such as high energy density batteries for transportation. Such devices would allow energy from stationary power plants, generated from fuels abundant in the U.S., to be exploited in mobile applications such as electric cars.

4. **Live Presence Communications**--the ability to intercommunicate in a way to obviate physical presence, thereby reducing the need for personal travel. Current teleconferencing is a primitive example. Communications technology does not appear to be the critical factor limiting more realistic interfacing; what requires research is deeper understanding of the mechanisms of inter-personal information transfer.

5. **Information Rationalization**--vastly improved techniques for extracting cogent information, rapidly and easily, from the growing number of databases.

6. **Accelerated Learning**--techniques for rapidly acquiring new industrial skills and for enhancing basic education processes.

7. **Artificial Reasoning**--technologies for constructing electronic and biotechnical systems, beyond the capability of robotics as we know them, capable of performing many of the higher-level functions of the human brain. Achievement of these technologies would represent the culmination of the body of ongoing research known as "Artificial Intelligence."

8. **Biotechnology**--advanced techniques for building "customized" biological systems. Examples of advanced industrial applications are microorganisms capable of concentrating metals from ores, systems capable of "growing" industrial materials with multiple properties, organic control devices, ultimately reasoning systems.

9. **Pattern Recognition**--technologies for interpreting sensory signals with discrimination and synthesis capabilities akin to humans.

10. **Medical Technology**--advanced methods for diagnosing and treating diseases and disfunctions and for restoring lost functions through use of advanced prostheses.

These pervasive technologies challenge current scientific and engineering knowledge. None can be expected to be fully realized in the near-term. However, their states of development are such that significant fruition can be projected for the 2005-2010 era.

- In examining NASA's long-term requirements to prepare the technology base for future space programs, we identified the need for:

  - **Fuels** with high specific impulse at high thrust

  - **Advanced materials** with low cost-to-strength ratios, to lower the cost of space transportation

  - Sophisticated techniques to reduce the high costs of **launch services**

  - Techniques for **automatic interpretation** of geometric-radiometric data from earth survey sensors

  - Technologies for manufacturing and deploying **large energy-collecting apertures** in GEO

  - Technologies to drastically reduce the life-cycle costs of **ground terminals** for satellite navigation systems

  - Techniques for enhancing the **performance-to-cost ratio of science missions**, by utilizing astronaut maintenance capabilities and by exploiting evolving capabilities for facile, interactive data bases.

- Many of the pervasive technologies applicable to industry are common with technologies NASA itself will need. NASA's inherent technological and managerial capabilities can be brought to bear to supplement industry in realizing these technologies.

- Presentation of the study's findings to representative Executive and Legislative personnel elicited, as an overall reaction, the view that the concept of NASA attempting to stimulate long-term basic industrial productivity was in consonance with trends in national science policy. The fact was noted that a number of federal agencies are beginning to move in directions evisioned by the study. Most of the reviewers expressed the view that NASA is the logical lead agency for such efforts.

CHAPTER 1

INTRODUCTION

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1.0 INTRODUCTION

1.1 OBJECTIVES OF THE STUDY

In accordance with its charter, NASA pursues the development of leading-edge technologies and capabilities, to enable the U.S. to undertake space missions. To what extent can these technologies and overall NASA capabilities also contribute to fulfilling other aspirations of the American people? The aim of this study is to assess the potential of NASA's technological capability to foster the development of long-term, innovative technologies that can strengthen the position of economic and societal leadership of the U.S. into the early 21st centry.

NASA's predecessor agency, NACA, performed a central role in conducting the advanced R&D that enabled the dramatic growth of the U.S. aircraft industry. At that time, the fledgling aircraft industry did not possess the capacity to carry on this research by itself. But it did have the capacity to exploit NACA's findings, with results that have benefited the whole nation.

A similar experience took place in the area of communication. Thanks to NASA's initial R&D in space communications, the American people now enjoy the most economical, highest quality satellite communications system in the world. That R&D also fostered the growth of the multibillion dollar communications satellite industry.

This study examines whether similar significant contributions to the U.S. economy can be repeated in other areas, to offset some of the negative trends affecting U.S. industrial leadership that have taken place during the last decade.

1.2 METHODOLOGY

The approach employed in this study is illustrated in Figure 1-1.

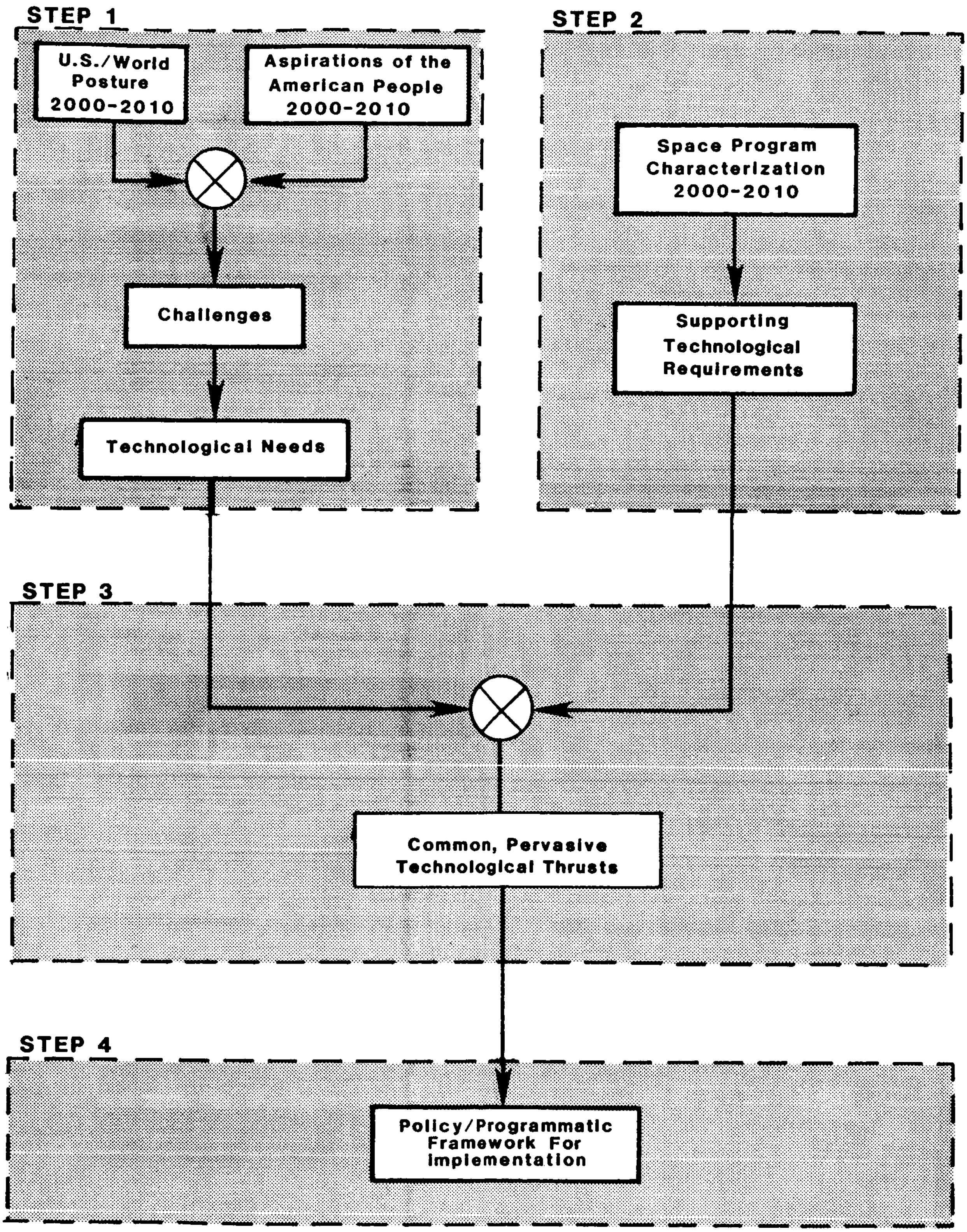

Figure 1-1. Study Approach

The **first** of the four major **steps** seeks to identify the advanced, innovative **technologies** that are needed to meet the nation's goals and aspirations in the **early 21st century.** The study examines two aspects: the technologies required to maintain a strong international economic posture; and the advanced capabilities that can contribute to fulfilling aspirations in other than economic areas, such as health, security and general well-being, described in our Constitution as "pursuit of happiness."

With respect to economic goals, the study analyzes the major sectors of the U.S. economy to establish the following factors:

- Current growth rates compared to historical growth patterns, and competitive posture vis-a-vis major foreign competitors;

- The reasons underlying unfavorable performance, e.g., flagging productivity;

- The degree to which long-term, innovative technologies might redress identified shortfalls.

The similar approach is taken with respect to the non-economic goals, leading to the identification of new technologies that support national aspirations in these areas, e.g., advanced health-restoring techniques.

The **second step** of the method seeks to identify key long-term technologies underlying future national **space missions.** The study characterizes the spectrum of missions with respect to their "utility" and derives the crucial, enabling technology drivers.

The **third step** compares the technologies identified in the first two steps and identifies **common, technological thrusts,** i.e., areas of R&D that meet the needs of both industry and the space program. These thrust areas represent directions in which application of NASA resources portends benefits transcending the space program itself.

The **fourth step** studies **mechanisms** NASA might choose to adopt to structure its technology efforts in these thrust areas to maximize their contribution to both space and other national needs.

1.3 GROUND RULES

In projecting the needs for advanced technology into the early 21st century, we adopted the following assumptions:

- Stable world--No disruptive wars, major social upheavals or ecological disasters.

- Stable economic trends--Economic conditions are extrapolated from current trends and serve as indicators, not forecasts of future conditions.

The data used for the study were drawn from the best available compilations. Table 1-1 summarizes the principal data sources. Where the data, particularly the foreign statistics, appeared of uncertain reliability, we supplemented them by interviews with private and governmental authorities.

TABLE 1-1

PRINCIPAL CATEGORIES AND MAJOR SOURCES OF DATA

CATEGORY	SOURCES
ECONOMICS	• ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT • UNITED NATIONS • WORLD BANK • CENTRAL INTELLIGENCE AGENCY
PRODUCTIVITY	• U.S. DEPARTMENT OF LABOR • JOHN W. KENDRICK, CONSULTANT • AMERICAN PRODUCTIVITY CENTER
INDUSTRIAL TECHNOLOGIES	• WORLD BANK • BUREAU OF THE CENSUS • U.S. DEPARTMENT OF LABOR • NATIONAL SCIENCE FOUNDATION • U.S. DEPARTMENT OF ENERGY
SPACE TECHNOLOGY	• NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • EUROPEAN SPACE AGENCY
DEMOGRAPHICS	• BUREAU OF THE CENSUS • AGENCY FOR INTERNATIONAL DEVELOPMENT
HEALTH	• WORLD HEALTH ORGANIZATION • U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
ENVIRONMENT	• ENVIRONMENTAL PROTECTION AGENCY • U.S. DEPARTMENT OF AGRICULTURE • ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT • U.S. COAST GUARD • THE CONSERVATION FOUNDATION • COUNCIL ON ENVIRONMENTAL QUALITY
CRIME	• FEDERAL BUREAU OF INVESTIGATION • INTERNATIONAL POLICE ORGANIZATION (INTERPOL) • U.S. DEPARTMENT OF JUSTICE
DISASTERS	• FEDERAL EMERGENCY MANAGEMENT AGENCY • U.S. GEOLOGICAL SURVEY • NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION • SMITHSONIAN INSTITUTION • AGENCY FOR INTERNATIONAL DEVELOPMENT
EDUCATION	• BUREAU OF THE CENSUS • ORGANIZATION FOR ECONOMIC COOPERATION AND DEVELOPMENT • NATIONAL SCIENCE FOUNDATION

CHAPTER 2

TECHNOLOGY REQUIREMENTS FOR SUPPORT OF MAJOR SECTORS OF THE ECONOMY

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2.0 **TECHNOLOGY REQUIREMENTS FOR SUPPORT OF MAJOR SECTORS OF THE ECONOMY**

2.1 OVERVIEW

This chapter summarizes the findings of the Step 1 process, Figure 1-1, which identified long-range requirements of U.S. industry for advanced technology.

Section 2.2 reviews the structure, outlook and needs of 20 major U.S. industrial sectors that we analyzed in detail.

Section 2.3 illustrates the analysis for a representative major industry, "Transportation Equipment." Sections B.1 through B.20, Volume II, detail the analyses for all twenty subsectors.

Section 2.4 summarizes the long-term technology requirements of the industries analyzed.

Section 2.5 identifies pervasive technologies common among the industries, whose attainment would benefit a broad class of industrial applications.

In this Study, we define advanced technologies in a special way. On the one hand, they transcend R&D efforts currently underway or planned by industry for the medium term, i.e., with expected fruition circa 1995. Nor, at the other extreme, are they so "blue sky" as to clearly lie beyond 2010. For example, coal-driven mobile energy is an ongoing program with medium-term fruition; mobile fusion was judged by us to lie beyond our time frame. Neither falls within our definition. On the other hand, we deem stationary-to-mobile energy storage as falling within our definition.

2.2 SELECTION OF CANDIDATE INDUSTRIES

To identify industry requirements for advanced technology and to assess technology's role in affecting economic growth, we selected industries from within two categories:

- "Sunset"--industries that have declined over the years, and/or are being eroded by foreign competition
- "Sunrise"--industries with performance above average, both domestically and with respect to foreign competitors.

In examining ongoing and planned technology development programs in the selected industries, we found that, in most industries, planning horizons do not extend beyond five to ten years. To test the study's hypothesis--that R&D associated with the long-term National Space Program could effectively stretch industry's horizon--we concentrated on long-term industrial needs, in the 2005 to 2010 time frame.

We arrived at our selection of twenty key industrial subsectors and component subdivisions through a top-down approach that began with analysis of the strengths and weaknesses of the U.S. economy as a whole, and progressed through the economy's major sectors, subsectors and subdivisions.

2.2.1 STRENGTHS AND WEAKNESSES OF THE U.S. ECONOMY

Two measures of the strengths of national economies in common use are Gross Domestic Product (GDP) and GDP per capita. GDP is the total yearly output of goods and services, valued at market prices, which originates from activities within a country. Figures 2-1 and 2-2 show the GDP and GDP per capita trends for the U.S. and for four major developed economies that most closely approach the U.S. Figures 2-3 and 2-4 show this data as ratios.

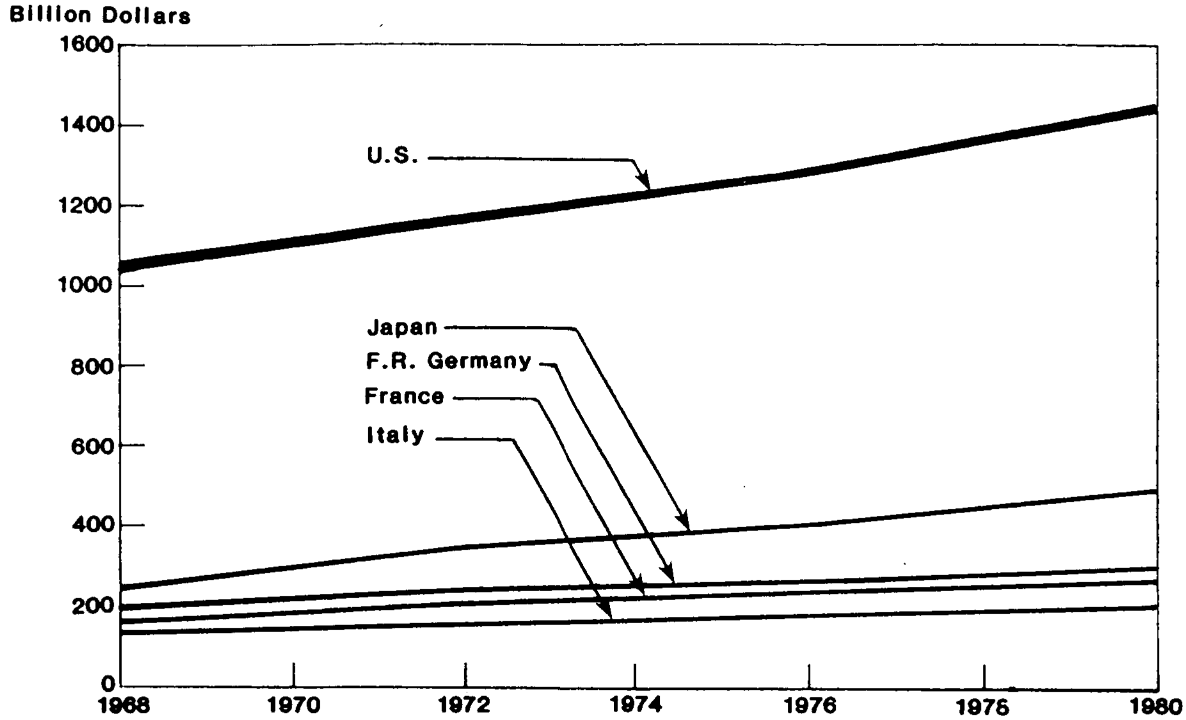
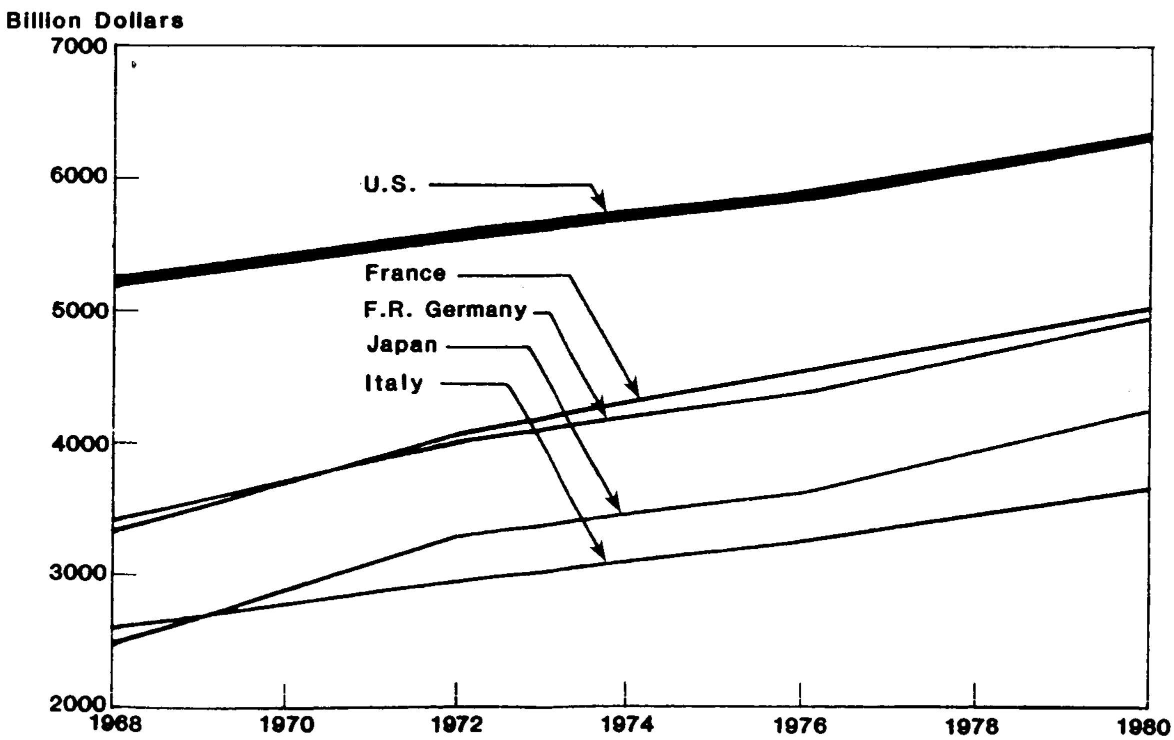


Figure 2-1. Trends in Gross Domestic Product



1972 Dollars, 1972 Rates Of Exchange

Figure 2-2. Trends in Gross Domestic Product Per Capita

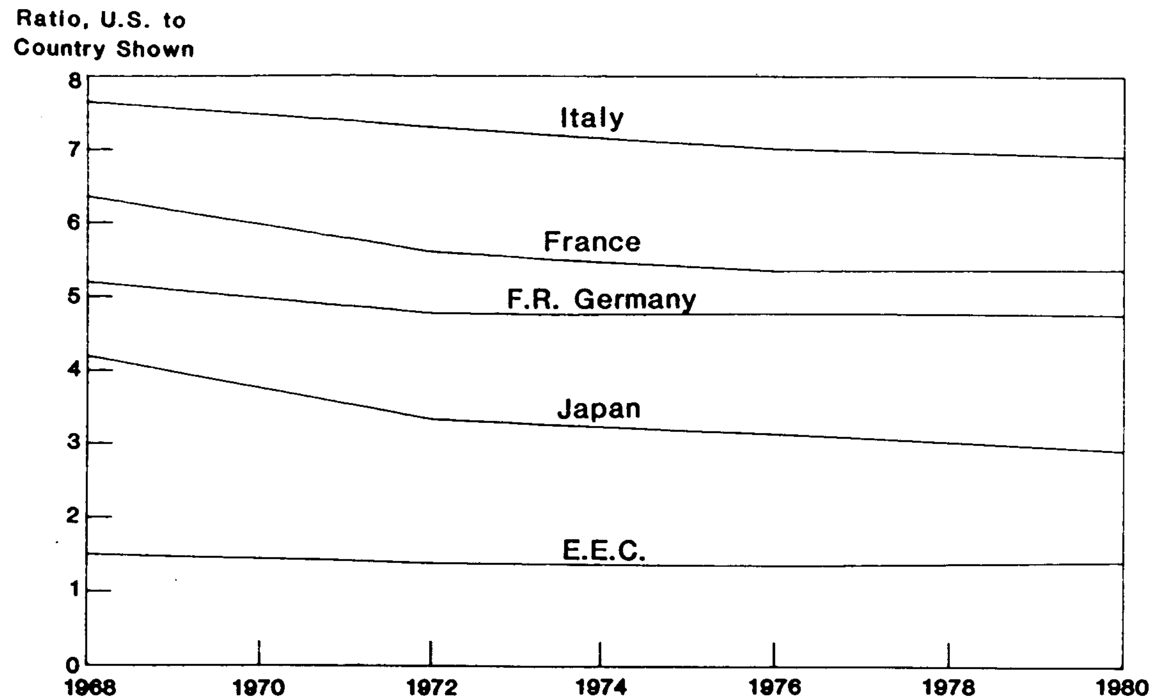


Figure 2-3. Ratio of Gross Domestic Product, U.S. and Foreign

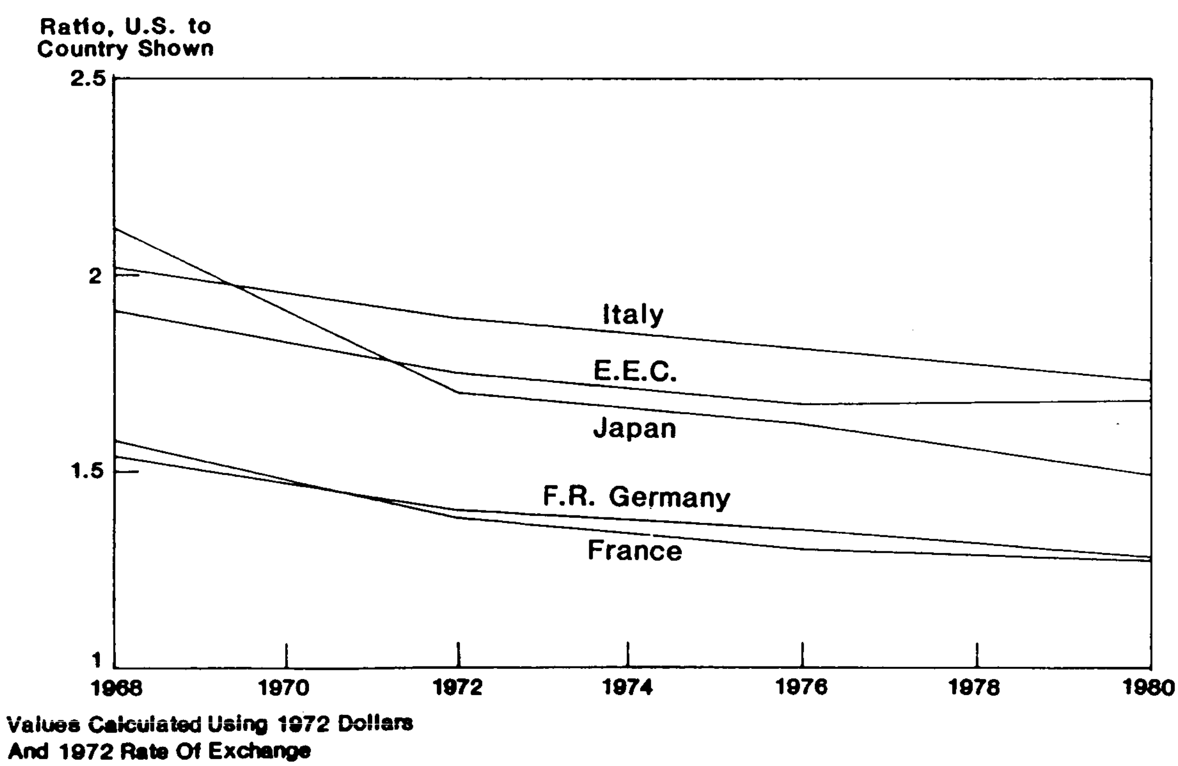


Figure 2-4. Ratio of Gross Domestic Product Per Capita, U.S. and Foreign

As shown in Figure 2-4, the U.S. lead in GDP per capita has been eroding.

Particularly significant is the fact that the U.S. slowdown in growth of GDP per capita has occurred even though a greater proportion of the U.S. population joined the work force during the last decade, see Table 2-1. Figure 2-5 shows that the growth of **GDP per person employed**, also termed **total labor productivity**, has declined relative to foreign economies. In contrast to annual growth rates in U.S. labor productivity of more than 3% over the period 1948-64, the growth rate dropped to approximately 1% between 1970 and 1982.

Several explanations have been advanced for this decline. Most economists ascribe it to a combination of aging plants, restrictive government regulations, entry of large numbers of inexperienced workers into the work force, and reduced outlays for R&D.[a] Some economists hold that a basic underlying causative factor is the fact that the U.S. is transitioning from an industrial to a service economy to a greater degree than other industrial nations, see Table 2-2. Productivity growth in service industries is generally held to be lower than that of manufacturing and agricultural sectors.

Clearly one needs to examine individual components of the economy in detail to establish which are responsible for the overall U.S. slowdown and which might be in need of revitalization.

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a Since 1982, there has been an improvement in labor productivity: U.S. growth rate now appears to be of order 3%. This improvement may be due to transient effects associated with post-recession recovery. Many of the long-term factors that contributed to the prior slowdown still affect the economy.

TABLE 2-1

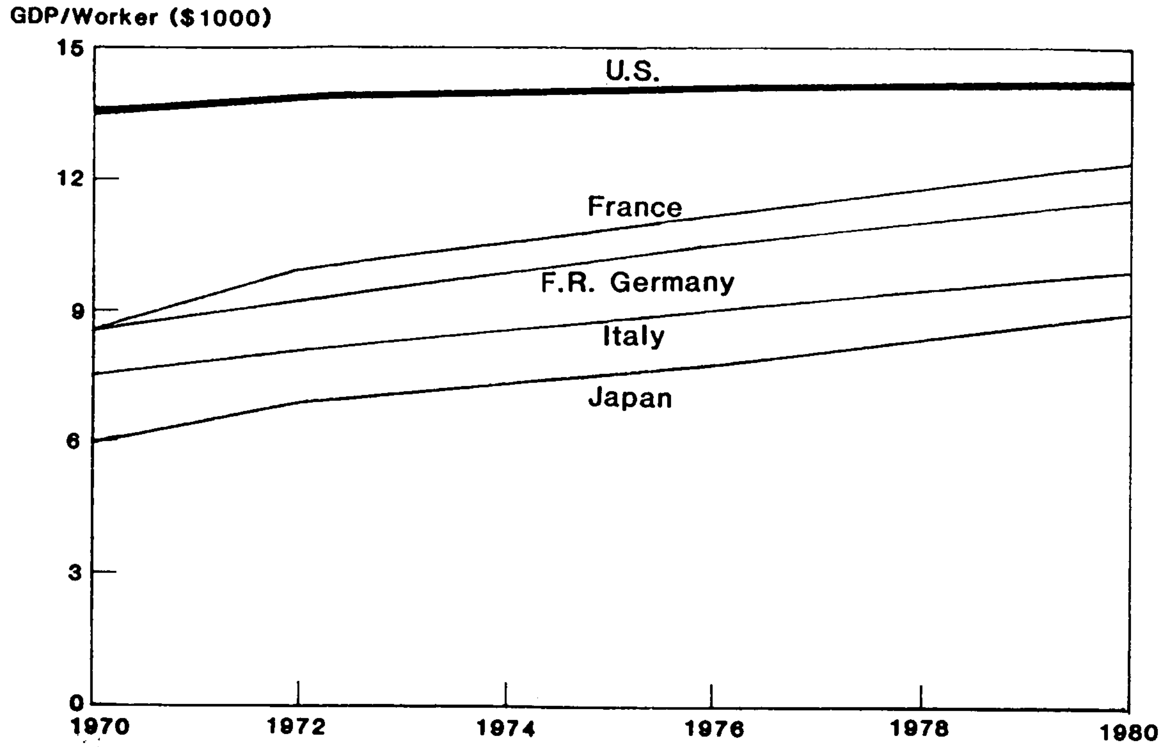
PERCENT OF TOTAL POPULATION EMPLOYED

COUNTRY	1970	1975	1981
U.S.	39.9	40.8	44.6
JAPAN	49.1	46.8	47.4
F.R. GERMANY	44.0	41.7	42.4
FRANCE	41.2	40.4	39.9
ITALY	36.9	36.0	37.0

TABLE 2-2

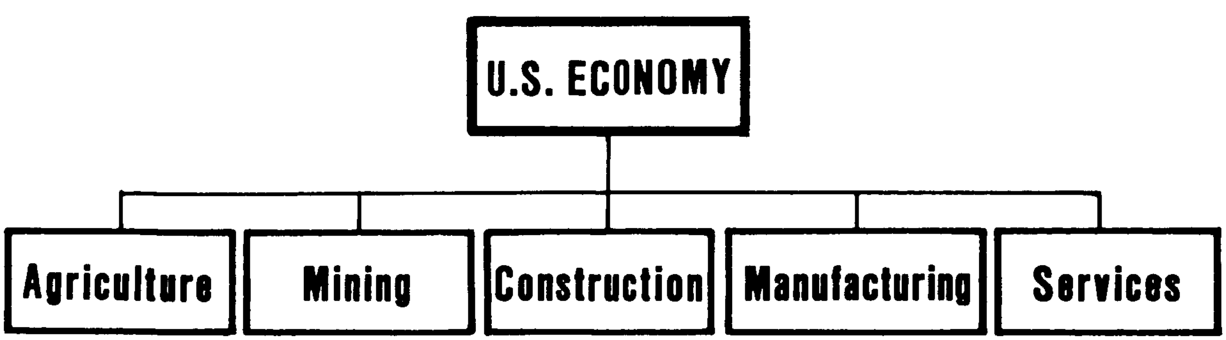
PERCENT OF CIVILIAN LABOR FORCE
IN THE SERVICE SECTOR

COUNTRY	1970	1975	1979
U.S.	59.2	60.8	62.4
JAPAN	46.9	51.1	53.4
F.R. GERMANY	42.	46.6	49.1
FRANCE	46.1	49.8	52.2
ITALY	38.1	41.5	43.8



1972 Dollars, 1972 Exchange Rates

Figure 2-5. GDP Per Employed Person (Labor Productivity)



Percent GNP (constant 1972 $)				
2.8	2.4	4.2	23.8	66.8

Figure 2-6. Ranking of the Sectors of the U.S. Economy, 1982

2.2.2 MAJOR ECONOMIC SECTORS

The U.S. economy comprises five major sectors as shown in Figure 2-6. Figure 2-7 shows the trends in productivity for the nonagricultural sectors. Several conclusions are evident:

- U.S. productivity appears to be diminishing or at best to be flat;
- Foreign productivity appears to be catching up;
- For the larger sectors, manufacturing and services, Japan appears to have the largest growth rate, Italy the lowest. We used Japan and Italy as "maximum-minimum" yardsticks for comparison.

Figure 2-8 shows labor productivity trend in agriculture, expressed both in monetary and physical terms, the latter in number of persons supported by each agricultural worker. To a significantly greater extent than indicated by the monetary data, the U.S. farmer is more productive than his foreign counterparts, and shows faster productivity growth. The apparent disparity between monetary and physical productivities is caused by multiple factors, such as differing price levels and presence of subsidies, and points to the limitations of measuring productivity solely in monetary terms.

Although measurement of productivity in physical terms presents notable difficulties vis-a-vis the more straighforward monetary indices, we have attempted to supplement monetary measurements with physical measurements wherever available.[b]

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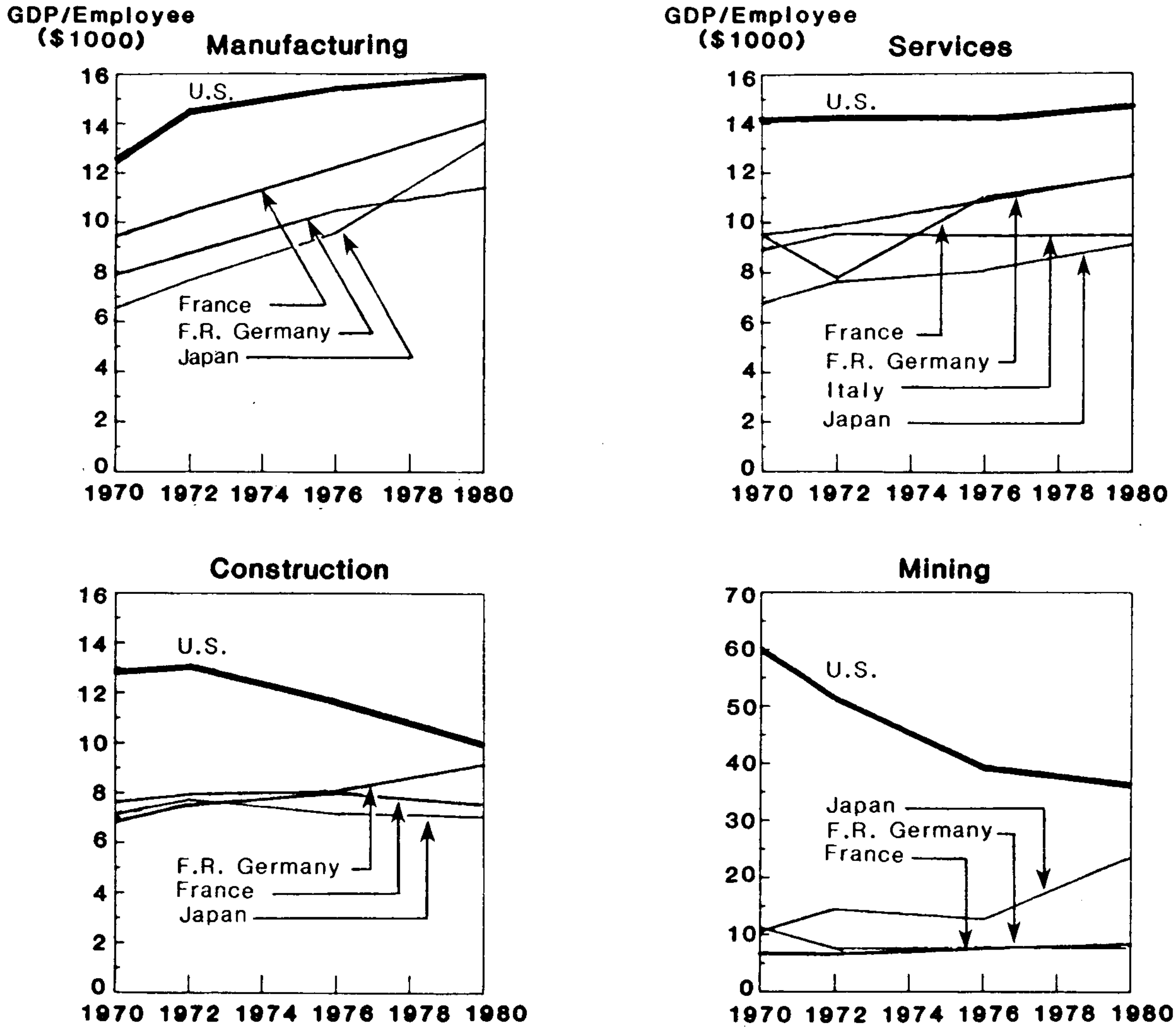
[b] The Bureau of Labor Statistics has been the lead agency in developing physical productivity measures. We acknowledge their assistance, particularly in making available much preliminary unpublished data.



Values calculated using
1972 dollars and 1972 exchange rate

Figure 2-7. Trends in Labor Productivity of the Major Economic Sectors

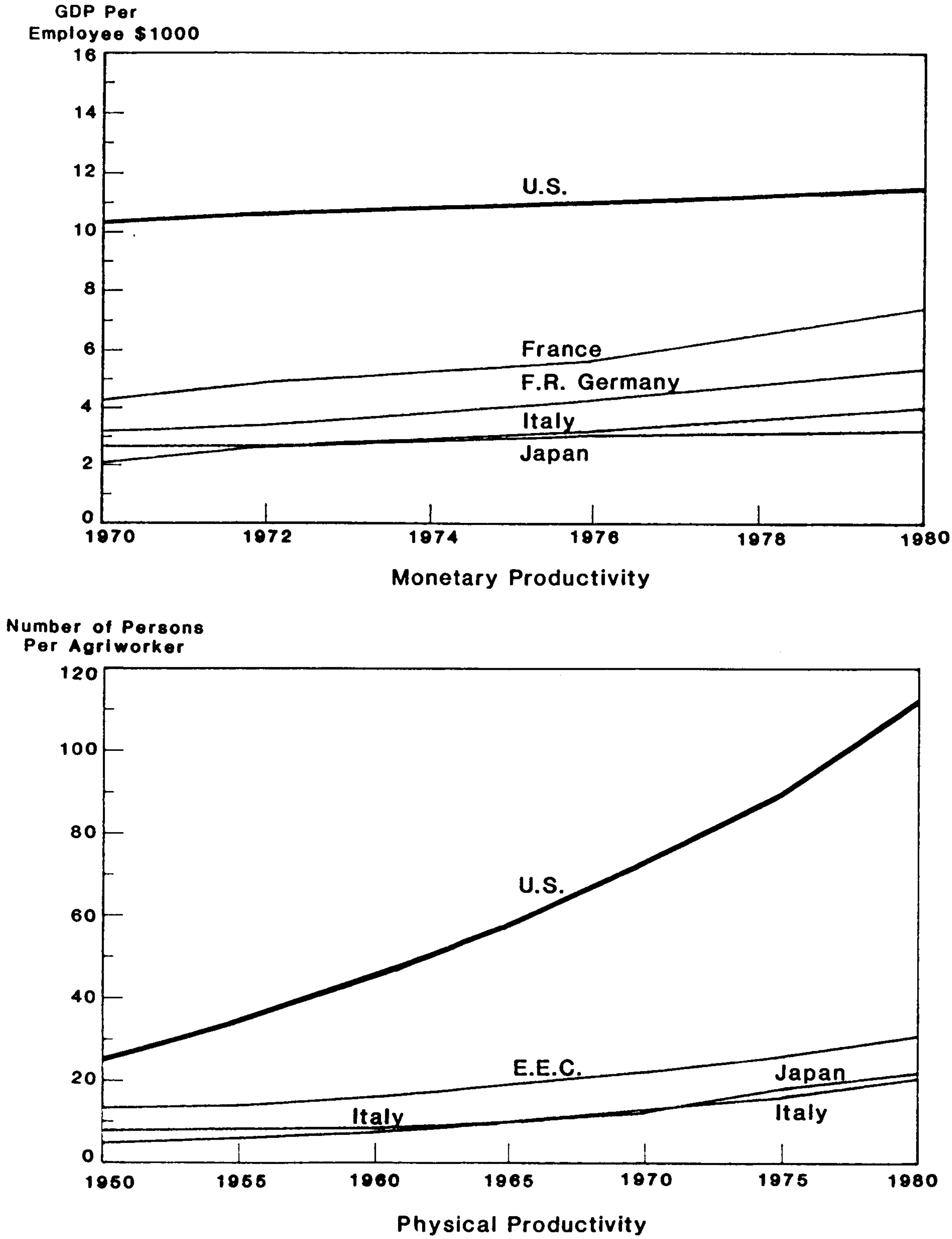


Figure 2-8. Labor Productivity in the Agricultural Sector

In selecting industries for detailed examination, we adopted the categorization of the Bureau of the Census Standard Industrial Classification (SIC). Major SIC categories are shown in Table 2-3.

Our choice of SIC manufacturing components was based on their contribution to GDP, Table 2-4, and their productivity trends. Figure 2-9 shows productivity trends for the top ten manufacturing subdivisions. Each panel compares subsector productivity with its Japanese equivalent. Through 1980, the curves represent actual historical data. Beyond 1980, they are simple extrapolations. These "future" curves are not to be considered as forecasts but simply as indicators of what might happen if conditions remained "as they are." The eras at which the curves intersect, may be considered "strategic indicators."

Figure 2-10 shows the productivity trends for the five subsectors within the service sector.

Analyzing these data to arrive at the most significant SIC categories to be studied, we selected the 20 subsectors shown in Table 2-5. For each subsector, the Table shows contribution to GDP, average annual productivity growth, and our assessment of the subsector's apparent "sunrise/sunset" condition. With the exception of "Transportation, Communication and Utility Services," SIC 40 through 49, all twenty subsectors show evidence of saturation or of "sunset" characteristics. Since each SIC subsector encompasses numerous industries, we reviewed each selected subdivision to uncover component industries with "sunrise" characteristics that may have been masked by the global statistics.

2.3 REPRESENTATIVE ANALYSIS OF SIC 37, TRANSPORTATION EQUIPMENT

As an example of the analysis process we applied to each of the twenty selected subsectors, this Section describes the condition and strengths/weaknesses of the transportation equip-

TABLE 2-3
THE SIC CLASSIFICATION

AGRICULTURE, FORESTRY, AND FISHING
01 AGRICULTURAL PRODUCTION—CROPS
02 AGRICULTURAL PRODUCTION—LIVESTOCK
07 AGRICULTURAL SERVICES
08 FORESTRY
09 FISHING, HUNTING, AND TRAPPING

MINING
10 METAL MINING
11 ANTHRACITE MINING
12 BITUMINOUS COAL AND LIGNITE MINING
13 OIL AND GAS EXTRACTION
14 MINING AND QUARRYING OF NONMETALLIC MINERALS, EXCEPT FUELS

CONSTRUCTION
15 BUILDING CONSTRUCTION—GENERAL CONTRACTORS AND OPERATIVE BUILDERS
16 CONSTRUCTION OTHER THAN BUILDING CONSTRUCTION—GENERAL CONTRACTORS
17 CONSTRUCTION—SPECIAL TRADE CONTRACTORS

MANUFACTURING
20 FOOD AND KINDRED PRODUCTS
21 TOBACCO MANUFACTURERS
22 TEXTILE, MILL PRODUCTS
23 APPAREL AND OTHER FINISHED PRODUCTS MADE FROM FABRICS AND SIMILAR MATERIALS
24 LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE
25 FURNITURE AND FIXTURES
26 PAPER AND ALLIED PRODUCTS
27 PRINTING, PUBLISHING, AND ALLIED PRODUCTS
28 CHEMICALS AND ALLIED PRODUCTS
29 PETROLEUM REFINING AND RELATED INDUSTRIES
30 RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS
31 LEATHER AND LEATHER PRODUCTS
32 STONE, CLAY, GLASS AND CONCRETE PRODUCTS
33 PRIMARY METAL INDUSTRIES
34 FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND TRANSPORTATION EQUIPMENT
35 MACHINERY, EXCEPT ELECTRICAL
36 ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT, AND SUPPLIES
37 TRANSPORTATION EQUIPMENT
38 MEASURING, ANALYZING, AND CONTROLLING INSTRUMENTS; PHOTOGRAPHIC, MEDICAL AND OPTICAL GOODS; WATCHES AND CLOCKS
39 MISCELLANEOUS MANUFACTURING INDUSTRIES

SERVICES
TRANSPORTATION, COMMUNICATIONS, ELECTRIC, GAS, AND SANITARY SERVICES
40 RAILROAD TRANSPORTATION
41 LOCAL AND SUBURBAN TRANSIT AND INTERURBAN HIGHWAY PASSENGER TRANSPORTATION
42 MOTOR FREIGHT TRANSPORTATION AND WAREHOUSING
43 U.S. POSTAL SERVICE
44 WATER TRANSPORTATION
45 TRANSPORTATION BY AIR
46 PIPE LINES, EXCEPT NATURAL GAS
47 TRANSPORTATION SERVICES
48 COMMUNICATION
49 ELECTRIC, GAS, AND SANITARY SERVICES

WHOLESALE TRADE
50 WHOLESALE TRADE—DURABLE GOODS
51 WHOLESALE TRADE—NONDURABLE GOODS

RETAIL TRADE
52 BUILDING MATERIALS, HARDWARE, GARDEN SUPPLY, AND MOBILE HOME DEALERS
53 GENERAL MERCHANDISE STORES
54 FOOD STORES
55 AUTOMOTIVE DEALERS AND GASOLINE SERVICE STATIONS
56 APPAREL AND ACCESSORY STORES
57 FURNITIRE, HOME FURNISHINGS, AND EQUIPMENT STORES
58 EATING AND DRINKING PLACES
59 MISCELLANEOUS RETAIL

FINANCE, INSURANCE, AND REAL ESTATE
60 BANKING
61 CREDIT AGENCIES OTHER THAN BANKS
62 SECURITY AND COMMODITY BROKERS, DEALERS, EXCHANGES, AND SERVICES
63 INSURANCE
64 INSURANCE AGENTS BROKERS, AND SERVICE
65 REAL ESTATE
66 COMBINATIONS OF REAL ESTATE, INSURANCE, LOANS, LAW OFFICES
67 HOLDING AND OTHER INVESTMENT OFFICES

SERVICES
70 HOTELS, ROOMING HOUSES, CAMPS, AND OTHER LODGING PLACES
72 PERSONAL SERVICES
73 BUSINESS SERVICES
75 AUTOMOTIVE REPAIR, SERVICES, AND GARAGES
76 MISCELLANEOUS REPAIR SERVICES
78 MOTION PICTURES
79 AMUSEMENT AND RECREATION SERVICES, EXCEPT MOTION PICTURES
80 HEALTH SERVICES
81 LEGAL SERVICES
82 EDUCATIONAL SERVICES
83 SOCIAL SERVICES
84 MUSEUMS, ART GALLERIES, BOTANICAL AND ZOOLOGICAL GARDENS
86 MEMBERSHIP ORGANIZATIONS
88 PRIVATE HOUSEHOLDS
89 MISCELLANEOUS SERVICES

PUBLIC ADMINISTRATION
91 EXECUTIVE, LEGISLATIVE, AND GENERAL GOVERNMENT, EXCEPT FINANCE
92 JUSTICE, PUBLIC ORDER, AND SAFETY
93 PUBLIC FINANCE, TAXATION, AND MONETARY POLICY
94 ADMINISTRATION OF HUMAN RESOURCES PROGRAMS
95 ADMINISTRATION OF ENVIRONMENTAL QUALITY AND HOUSING PROGRAMS
96 ADMINISTRATION OF ECONOMIC PROGRAMS
97 NATIONAL SECURITY AND INTERNATIONAL AFFAIRS

NONCLASSIFIABLE ESTABLISHMENTS
99 NONCLASSIFIABLE ESTABLISHMENTS

TABLE 2-4

SUBSECTOR CONTRIBUTION TO U.S. MANUFACTURING'S PORTION OF THE GDP IN 1980

	SIC CODE	SUBSECTOR	%	CUMULATIVE %
TOP TEN MAJOR SUB-SEC-TORS	35	MACHINERY EXCEPT ELECTRICAL	12.9	12.9
	37	TRANSPORTATION EQUIPMENT INCL. MOTOR VEHICLES	9.4	22.3
	36	ELECTRIC & ELECTRONIC MACH.	9.2	31.5
	20	FOOD & KINDRED PRODUCTS	7.9	39.4
	34	FABRICATED METAL PRODUCTS	7.8	47.2
	33	PRIMARY METALS	7.3	54.5
	28	CHEMICAL & ALLIED PRODUCTS	7.2	61.7
	29	PETROLEUM & RELATED INDUS.	6.9	68.6
	27	PRINTING & PUBLISHING	5.4	74.0
	26	PAPER & ALLIED PRODUCTS	3.7	77.7
	38	INSTRUMENTS AND RELATED PRODUCTS	3.3	81.0
	32	STONE, CLAY & GLASS	3.1	84.1
	23	APPAREL & OTHER TEXTILE PRODUCTS	3.0	87.1
	30	RUBBER & MISC. PLASTICS	2.9	90.0
	24	LUMBER & WOOD	2.9	92.9
	22	TEXTILE MILL PRODUCTS	2.6	95.5
	39	MISC. MANUFACTURING	1.5	97.0
	25	FURNITURE & FIXTURES	1.5	98.5
	21	TOBACCO MANUFACTURING	0.8	99.3
	31	LEATHER & LEATHER PRODUCTS	0.7	100.0
	20-39	ALL MANUFACTURING	100	

TABLE 2-5

CHARACTERISTICS OF THE TWENTY SELECTED SUBSECTORS

SIC CODE	SUBSECTOR	CONTRIBUTION TO GDP (1980) %	AVERAGE ANNUAL PRODUCTIVITY GROWTH %/YEAR (1972-80)	APPARENT SUNRISE/SUNSET CONDITION
35	MACHINERY EXCEPT ELECTRICAL	3.1	1.5	SIC 354-SUNSET, SIC 357-SUNRISE, SIC 351-SATURATED
37	TRANSPORTATION EQUIPMENT	2.2	0.5	SATURATED TO SUNRISE
36	ELECTRIC & ELECTRONIC EQUIPMENT	2.2	1.6	SUNRISE
20	FOOD & KINDRED PRODUCTS	1.9	2.4	SATURATED
34	FABRICATED METAL PRODUCTS	1.9	1.3	SUNSET
33	PRIMARY METAL INDUSTRIES	1.7	2.3	SUNSET
28	CHEMICAL & ALLIED PRODUCTS	1.7	1.9	SATURATED TO SUNRISE
29	PETROLEUM REFINING & RELATED INDUSTRIES	1.6	2.2	SATURATED
27	PRINTING, PUBLISHING AND ALLIED PRODUCTS	1.3	0.4	SATURATED
26	PAPER & ALLIED PRODUCTS	0.9	2.8	SATURATED
38	INSTRUMENTS & RELATED PRODUCTS	0.8	1.0	SATURATED TO SUNRISE
32	STONE, CLAY & GLASS	0.7	1.1	SATURATED TO SUNRISE
30	RUBBER & MISC. PLASTICS PRODUCTS	0.7	-0.6	SATURATED
50-59	WHOLESALE & RETAIL TRADE	15.1	0.2	SATURATED
90-97	GOVERNMENT & GOVERNMENT ENTERPRISES	14.6	-0.3	SATURATED
60-67	FINANCE, INSURANCE, & REAL ESTATE	14.1	0.1	SATURATED
41,42,44-47	TRANSPORTATION SERVICES	3.9	1.9	SIC 401-SUNSET,SIC 42-SATURATED,SIC 45-SUNRISE,SIC 44-SATURATED
48	COMMUNICATION SERVICES	2.3	1.9	SUNRISE
15-17	CONSTRUCTION	3.4	-2.24	SATURATED
10-14	MINING	1.5	N/A	SATURATED

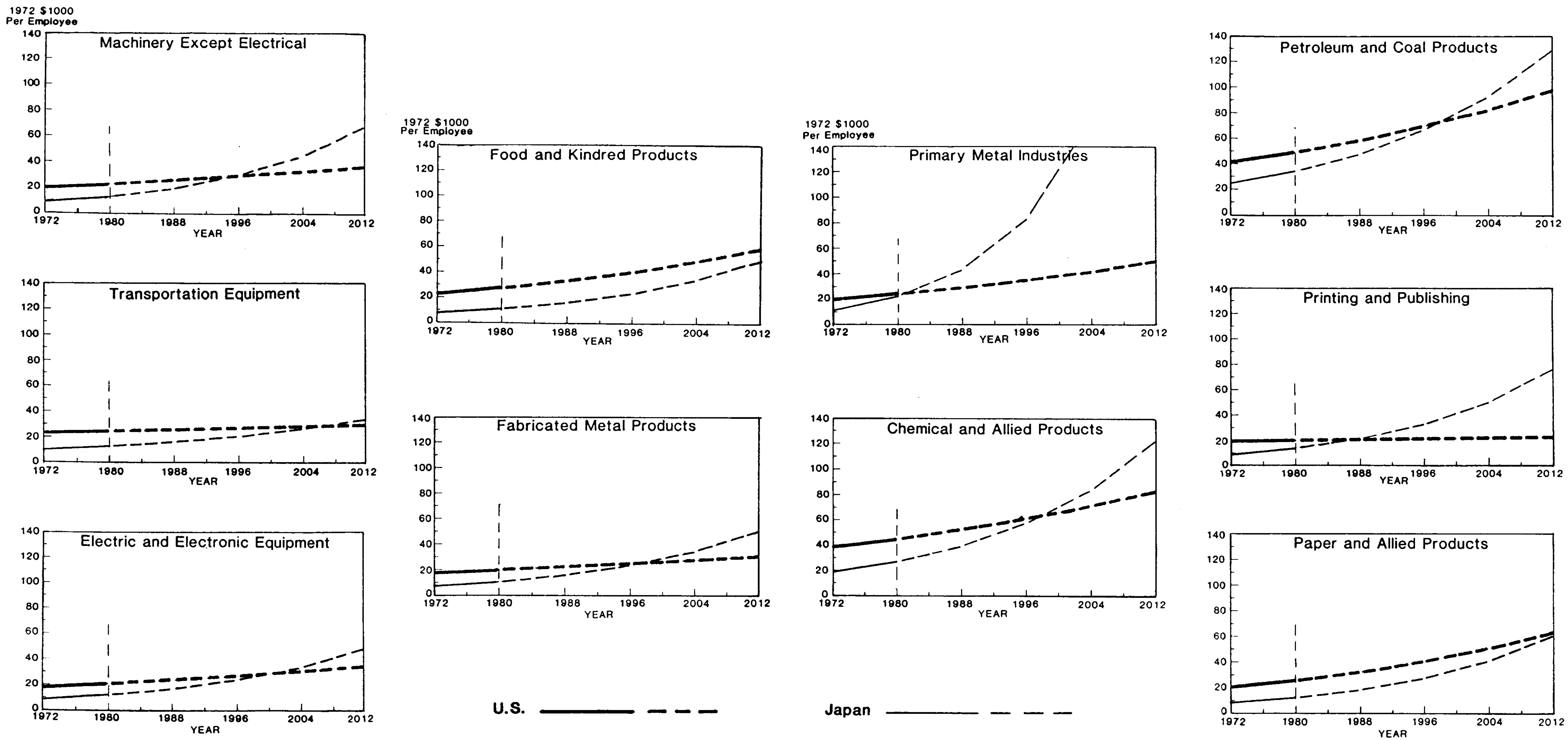


Figure 2-9. Productivity of Ten Selected Manufacturing Subsectors

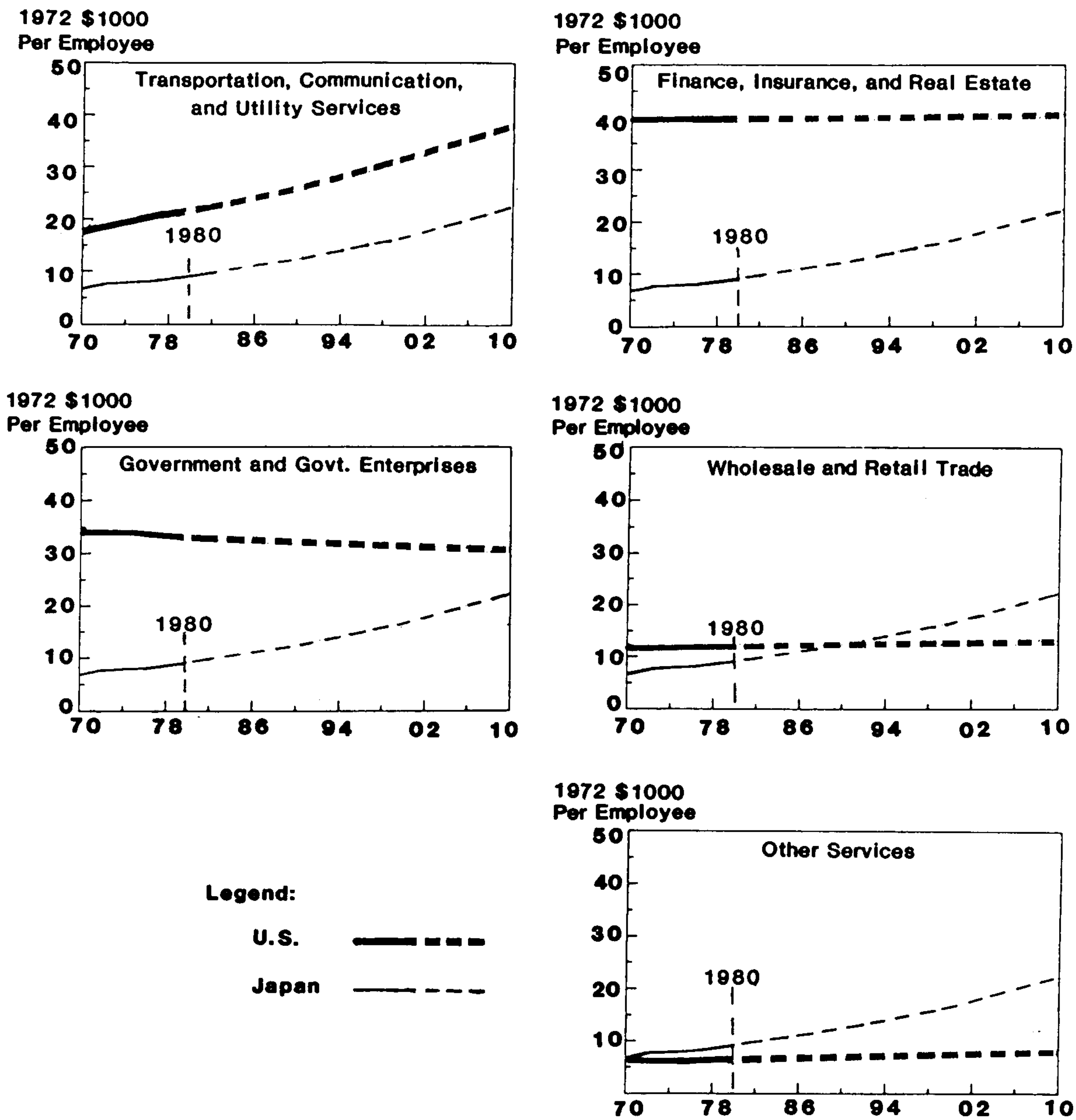


Figure 2-10. Productivity Trends of Service Subsectors

ment industry. It shows the current direction of its technology development effort and identifies the industry's need for "leap-frog" technology advances. The analyses of the other 19 subsectors are presented in Volume II, Sections B.1 through B.20.

The transportation equipment subsector, SIC 37, includes establishments engaged in manufacturing equipment for transportation of passengers and cargo by land, air and water. The subsector accounted (in value added) for 9.9% of the manufacturing sector's contribution to GDP in 1980. Second only to Machinery except Electrical, SIC 35, the subsector is characterized by:

- A high degree of fragmentation. Out of a total of approximately 10,000 establishments, 6,500 employed fewer than 20 persons (1977).

- A labor productivity of $24,224 per employee year or $12.62 per employee hour (1980, 1972 $), ranking this subsector ninth among the nation's 20 manufacturing subsectors. A compound annual labor productivity growth rate average of 0.5%/year from 1972 to 1980 ranks this subsector fifteenth. The labor productivity for the comparable Japanese subsector was $13,875 per employee year or $7.23 per employee hour (1980, 1972 $), ranking this subsector fifth among Japan's 20 manufacturing subsectors. The compound annual labor productivity growth rate for the Japanese subsector averaged 4.2%/year from 1972 to 1980, ranking this subsector eighteenth.

- A somewhat less intensive capital investment base relative to other subsectors within the manufacturing sector. Capital investment amounted to $15,032 in total assets per worker, ranking ninth in terms of (depreciated) fixed assets (1980, 1972 $). New yearly capital expenditures were $2,517 per employee (1980, 1972 $)

ranking seventh in the manufacturing sector. Total capital productivity, measured as dollars of added value output per dollar of capital investment was 0.63 (1981).

- An aggressive R&D program. For the subsector as a whole, R&D expenditures amounted to $8 billion (1980, 1972 $), ranking it first among the 20 manufacturing subsectors. R&D expenditures were equivalent to 18.7% of the value added by the subsector in 1980.

Table 2-6 shows the major products of each component of the transportation equipment subsector, ranked in descending order in terms of share of the subsector's contribution to GDP in 1980. Table 2-7 characterizes their principal economic measures.

As shown, two subdivisions--Motor Vehicles and Equipment (SIC 371) and Aircraft and Parts (SIC 372)--accounted for 76% of the subsector's output in 1980. Another subdivision (SIC 376), Guided Missiles, Space Vehicles and Parts, which accounted for an additional 10%, is important because of its use of the most advanced technology. In assessing long-term technology needs, we selected these three subdivisions for detailed analysis. These are described in Volume II, Section B.2. The analysis of the motor vehicle subdivision (SIC 371) is described following.

2.3.1 MOTOR VEHICLES (SIC 371)

This subdivision includes establishments that manufacture completed motor vehicles and motor vehicle parts, but does not include establishments that solely manufacture motor vehicle parts.

In 1977, the last "normal" year in the recent past, the motor vehicle subdivision (SIC 371) accounted for 51% of the added value and 65% of the shipments in the motor vehicle and

TABLE 2-6

CLASSIFICATION OF MAJOR PRODUCTS OF THE TRANSPORTATION EQUIPMENT INDUSTRY (SIC 37) AND RELATIVE CONTRIBUTION TO TOTAL SUBSECTOR OUTPUT, 1980

SIC CODE	SUBDIVISION DESIGNATION AND TYPICAL PRODUCTS	% CONTRIBUTION
371	**MOTOR VEHICLES AND EQUIPMENT** AUTOMOBILES, TRUCKS, COMMERCIAL CARS AND BUSES, SPECIAL PURPOSE MOTOR VEHICLES, MOTOR VEHICLE BODIES AND TRUCK TRAILERS, MOTOR VEHICLE PARTS AND ACCESSORIES.	39.9
372	**AIRCRAFT AND PARTS** AIRCRAFT, AIRCRAFT ENGINES AND PARTS, AUXILIARY EQUIPMENT AND ASSOCIATED R&D.	36.1
376	**GUIDED MISSILES, SPACE VEHICLES AND PARTS** GUIDED MISSILES, SPACE VEHICLES, SPACE PROPULSION UNITS, PARTS AND AUXILIARY EQUIPMENT AND ASSOCIATED R&D.	9.6
373	**SHIP AND BOAT BUILDING AND REPAIR** SHIPS, BOATS, BARGES AND LIGHTERS.	8.2
374	**RAILROAD EQUIPMENT** LOCOMOTIVES, RAILROAD, STREET AND RAPID TRANSIT CARS AND CAR EQUIPMENT.	4.2
379	**MISCELLANEOUS TRANSPORTATION EQUIPMENT** TRAVEL TRAILERS AND ATTACHMENTS FOR PICK-UP TRUCKS AND MOTOR HOMES, MILITARY TANKS AND OTHER TRANSPORTATION EQUIPMENT.	1.4
375	**MOTORCYCLES, BICYCLES, AND PARTS** MOTORCYCLES, BICYCLES AND ASSOCIATED PARTS AND EQUIPMENT.	0.6
37	ALL TRANSPORTATION EQUIPMENT	100.0

SOURCES: U.S. DOC/BOC: STATISTICAL ABSTRACT OF THE U.S., 1982-3
EOP/OMB: STANDARD INDUSTRIAL CLASSIFICATION MANUAL, 1972

TABLE 2-7

SUBDIVISIONS AND CHARACTERIZATION OF TRANSPORTATION EQUIPMENT INDUSTRY (SIC 37), 1980, IN 1972 DOLLARS

SUBDIVISION	PERCENTAGE CONTRIBUTION	EMPLOYEES (1000)	NUMBER OF ESTABLISHMENTS[a]			GROSS VALUE OF FIXED ASSETS ($/EMPLOYEE)	NEW CAPITAL EXPENDITURES ($/EMPLOYEE)	LABOR PRODUCTIVITY ($/EMPLOYEE)
			TOTAL	LESS THAN 20 EMPLOYEES	100 OR MORE EMPLOYEES			
ALL TRANS-PORTATION EQUIP. (37)	100	1772.1	10,176	6,518	1,561	15,032	2,517	24,224
MOTOR VEHICLES AND EQUIP. (371)	40	714.3	4,234	2,526	802	23,718	4,274	23,949
AIRCRAFT AND PARTS (372)	36	580.5	1,173	624	253	9,640	1,562	26,669
SHIP AND BOAT BUILDING AND REPAIR (373)	8	218.6	2,795	2,059	261	8,294	845	16,071
RAILROAD EQUIP. (374)	4	65.2	201	83	66	11,101	1,442	27,654
MOTORCYCLES, BICYCLES AND PARTS (375)	1	15.2	350	287	19	8,735	811	17,519
GUIDED MISSILES, SPACE VEHICLES AND PARTS (376)	10	140.7	109	18	64	8,459	1,217	29,176
MISCELLANEOUS	1	37.6	1,314	921	96	6,386	1,015	17,342

[a] 1977

SOURCE: U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOC/BOC: ANNUAL SURVEY OF MANUFACTURES, 1981

equipment industry. The period following 1977 marked a crisis in the industry. Strong import competition, shifts in consumer preferences, and poor sales due to economic recession caused the years 1980 and 1981 to be the bleakest in the industry's history. Although the industry has made a significant recovery in 1983 and 1984, the long-term outlook is uncertain.

The subdivision's historical and current posture is summarized in Tables 2-8 and 2-9, which portray the industry's business and structural profiles, respectively. Table 2-8 shows that, expressed in constant 1972 dollars, industry shipments have increased only 13% in eleven years, from $42.9 billion in 1972 to $48.8 billion in 1983. Because of the recent economic recovery, the 1984 forecast is for shipments of $54.2 billion (in 1972 $), an increase of 11.1% over 1983. Employment has steadily declined, falling by 22%, from 339,000 in 1972 to 265,000 in 1983. Labor productivity, i.e., output per employee hour, rose fairly steadily until 1977. A stasis was experienced during the next three years, currently being followed by an upward swing.

Table 2-9 shows that the motor vehicle industry is dominated by four firms, comprising 14% of the subdivision's establishments and accounting for approximately 97% of the output. The remaining 278 establishments are operated by 250 companies that manufacture truck tractors and specialty vehicles (such as stretch limousines, replica antique cars, and limited production sports cars). Of these establishments, 203 or 63% have fewer than 20 employees.

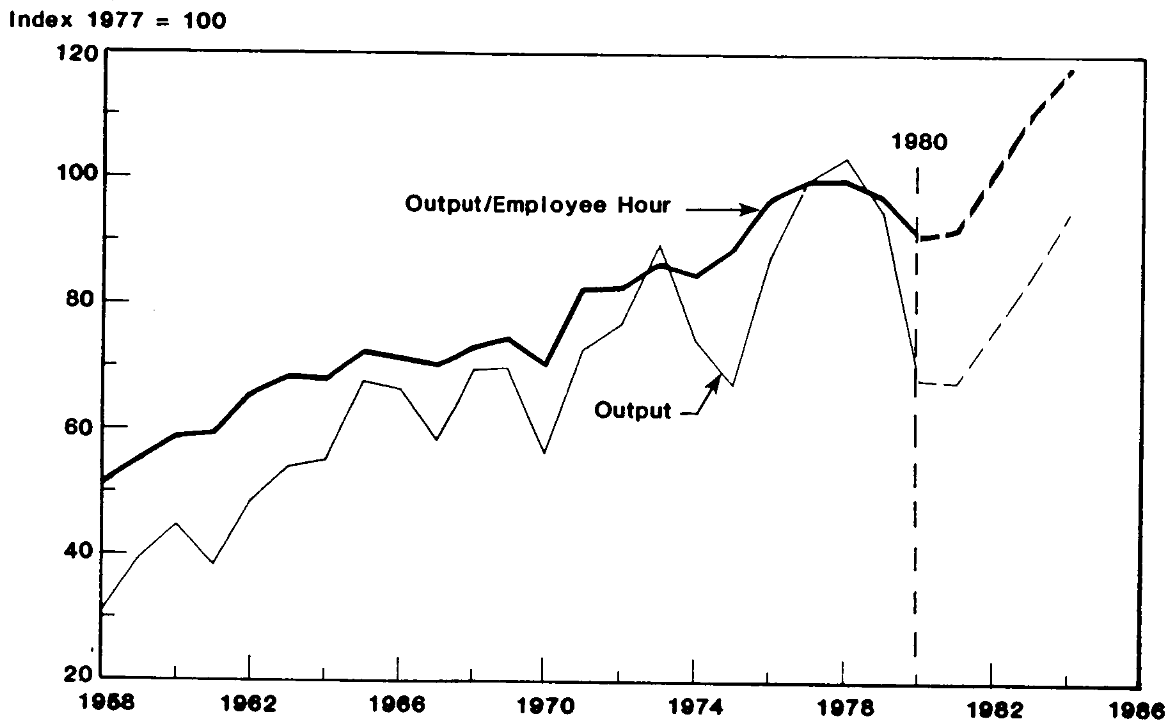
As shown in Table 2-9, the cost of the finished product is dominated by the cost of input materials (75%). Importantly, manufacturing labor represents only 7% of total costs and is expected to shrink as greater levels of automation are adopted.

A major category of input materials consist of manufactured parts from domestic and foreign manufacturers. They range from

TABLE 2-8

BUSINESS PROFILE OF THE
MOTOR VEHICLE INDUSTRY (SIC 371)

	1972	1977	1979	1981	1983	1984 EST
SHIPMENTS (BILLION $)						
CURRENT $	42.9	76.5	85.1	74.3	97.9	120
1972 $	42.9	57.2	54.9	40.5	48.8	54.2
TOTAL EMPLOYMENT (THOUSANDS)	339.2	343.6	398.5	271.9	265.0	275.0



	1978	1982	1983	1984 EST
PLANT CAPACITY UTILIZATION, %	93	53	69	75

NET PROFIT MARGIN AFTER TAXES, % 3.6-5.0

VALUE OF PLANT, 1976, CURRENT $ BILLION 6.8

	1977	1981
NEW CAPITAL EXPENDITURE, CURRENT $ BILLION	1.7	4.7

DEALER INVENTORY, END OF 1983 2.4 MONTHS

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
U.S. DOL/BLS: VALUE-LINE INVESTMENT SURVEY, 1984

TABLE 2-9

STRUCTURAL PROFILE OF THE
MOTOR VEHICLE INDUSTRY (SIC 371)

ESTABLISHMENTS (1977) (CATEGORIZED BY NO. OF EMPLOYEES)		LEADING FIRMS (1983) NAME	PERCENT INDUSTRY OUTPUT	NUMBER OF ESTABLISHMENTS
SMALL (<20)	203	GENERAL MOTORS	58.7	21
INTERMEDIATE (20-1000)	53	FORD MOTOR	22.8	14
LARGE (>1000)	66	CHRYSLER CORP.	13.0	7
		AMERICAN MOTORS	3.0	2
TOTAL (254 COMPANIES)	322	TOTAL	97.5	44

	MFG. LABOR	OTHER LABOR	MATERIALS	ENERGY	CAPITAL
PRODUCTION COST DISTRIBUTION, 1977	7%	2%	75%	0.5%	15%

R&D EXPENDITURES (SIC 371)	1972	1976
CURRENT $, BILLION/YEAR	2.0	2.8

RETOOLING EXPENDITURES (SIC 711)	1978-1982
CURRENT $ BILLION	51.0

AVERAGE ANNUAL COST OF AIR POLLUTION CONTROL (ALL SIC 37)	1970-1978	1981-1990
(BILLION $, 1972)	3.05	4.02

PASSENGER CAR PRODUCTION

CAPACITY, MILLION UNITS	1978	1982	1982, % of 1978
TOTAL	10	12	120
SMALL CAR	1.4	3.9	279
FRONT WHEEL DRIVE TRANSAXLE	1.2	3.6	300
4-CYCLINDER ENGINE	1.0	4.2	420
V-8 ENGINE	5.7	3.7	65

SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
U.S. DOC/BOC: CENSUS OF MANUFACTURES, 1977
VALUE-LINE INVESTMENT SURVEY, 1984
EPA: 1984 COST OF CLEAN AIR AND WATER REPORT TO CONGRESS

electronic parts to bumpers, batteries and engines. Precise data on the composition and costs of these input materials are considered proprietary by the industry, and are not officially available. Pertinent data derived from the BLS 1972 Input-Output Table are shown in Figure 2-11. The most costly input material, accounting for nearly half of the value, is motor vehicle parts. The following basic materials emerge as the major input materials (with the manufactured motor vehicle parts segmented into its input materials): stampings and other fabricated metal products (26.2%), steel (25.5%), rubber and plastics (6.9%), machinery including engines (5.5%), glass (4.0%), fabricated textile products (4.0%), and batteries and electrical products (3.9%).

Major structural changes have occurred in the automobile industry since 1978. After a long period of stagnation the industry began to make large investments--$51 billion (in current $) in the four years 1978 to 1982--reflecting a major shift in emphasis from large to small autos. Much of this investment was spent in restructuring the production mix from large standard cars to cars that are smaller, have 4-cylinder instead of 8-cylinder engines, and are equipped with front-wheel drive instead of rear-wheel drive transaxles, see Table 2-9.

Among the institutional factors which influence/constrain the industry, four stand out. As shown in Table 2-10, the industry is strongly affected by congressional and government agency rule making, and by numerous government regulations ranging from safety to fuel economy. Historically, industry sales have been affected by oil prices, interest rates, and the business cycle. These same factors, however, also tend to constrain the sale of imports. Two additional factors tend to restrain sales with respect to foreign imports. First, labor relations are characterized by a large labor union influence that has resulted in generous collective bargaining agreements not infrequently exceeding the industry's labor productivity gains. Second,

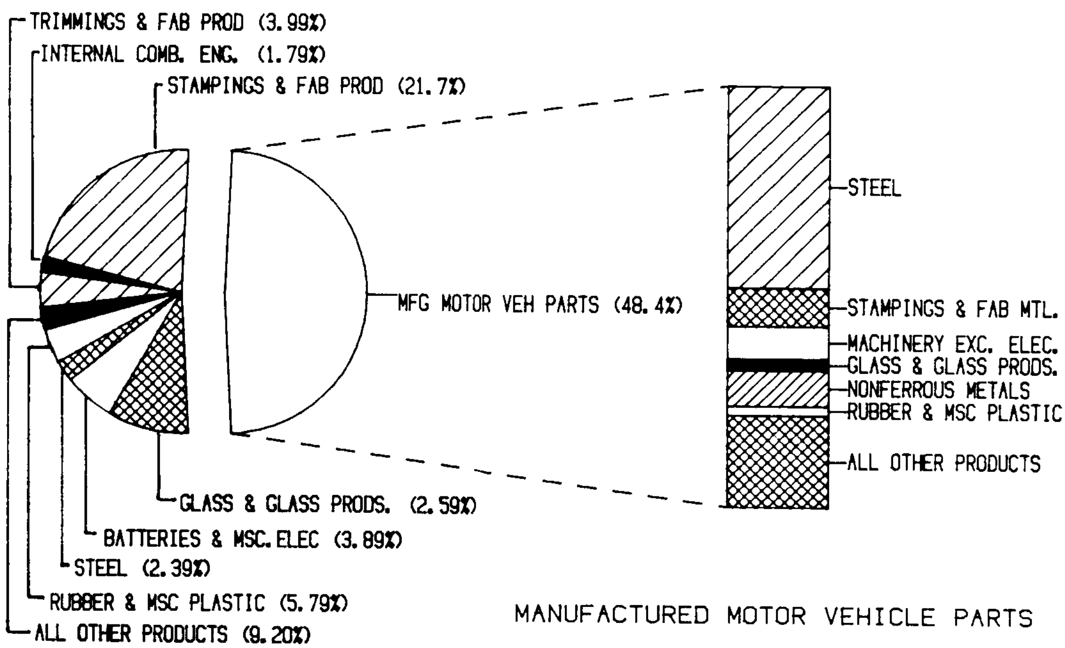


Figure 2-11. Composition of Materials for the Motor Vehicle Industry

TABLE 2-10

DOMINANT CONSTRAINTS AFFECTING THE
MOTOR VEHICLE INDUSTRY (SIC 371)

GOVERNMENT REGULATIONS	NUMEROUS DEALINGS WITH SAFETY EXHAUST EMISSIONS, AND FUEL ECONOMY REGULATIONS AFFECT EACH FIRM DIFFERENTLY, AND ALTER RELATIVE COMPETITIVE POSITIONS. FOR EXAMPLE, 237 REGULATORY CHANGES FROM 1960 THROUGH 1975.
FUEL PRICES	SALES AFFECTED BY OIL PRICES, AUTOMOBILES USE 42% OF ALL OIL CONSUMED IN U.S.
LABOR RELATIONS	GENEROUS COLLECTIVE BARGAINING AGREEMENTS WITH LARGE UNION PRESENCE; HIGH ABSENTEEISM (5.7% OF EMPLOYEE HOURS FOR U.S. VERSUS 0.5-1.0% FOR JAPAN).

YEAR	TARGET	STRIKE
1964	CHRYSLER	10 DAYS
1967	FORD	49 DAYS
1970	GMC	67 DAYS
1973	CHRYSLER	9 DAYS
1976	FORD	28 DAYS
1979	GMC	NO STRIKE
1982	NONE	NO STRIKE

FISCAL/MONETARY POLICY	AUTOMOBILE SALES ADVERSELY AFFECTED BY HIGH INTEREST RATES.

SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

absenteeism has been significantly larger (5.7%) with respect to Japanese experience (less than 1%).

Competitive Issues Affecting the Motor Vehicle Industry

Table 2-11 summarizes export and import statistics and illustrates the fact that the industry is under siege. Imports currently account for almost 30% of automobile unit sales; when measured in dollars, these imports have increased at an average annual rate of 16.4% during 1972-83, while exports have grown at only 3.7% during the same period. Automobile production in the U.S. has dropped to eight million units in 1982 from 9.6 million in 1965 (after a peak of over eleven million in 1978). Japanese production has risen from 0.7 million to over seven million over the same time period, while Italian production has remained flat at about one million. Without quotas for Japanese manufactures, domestic automobile production may have been even more severely impacted. This shift towards imports on the part of the U.S. public has been superficially attributed to a shift in consumer preferences from large to small cars, induced in part by high fuel costs, and in part by increasing traffic congestion, e.g., parking problems. A deeper evaluation however, shows that U.S. manufacturers could and did produce smaller cars, but that these failed to sell because of three principal factors vis-a-vis the foreign product:

- Lower product quality,
- Lower reliability,
- Higher cost.

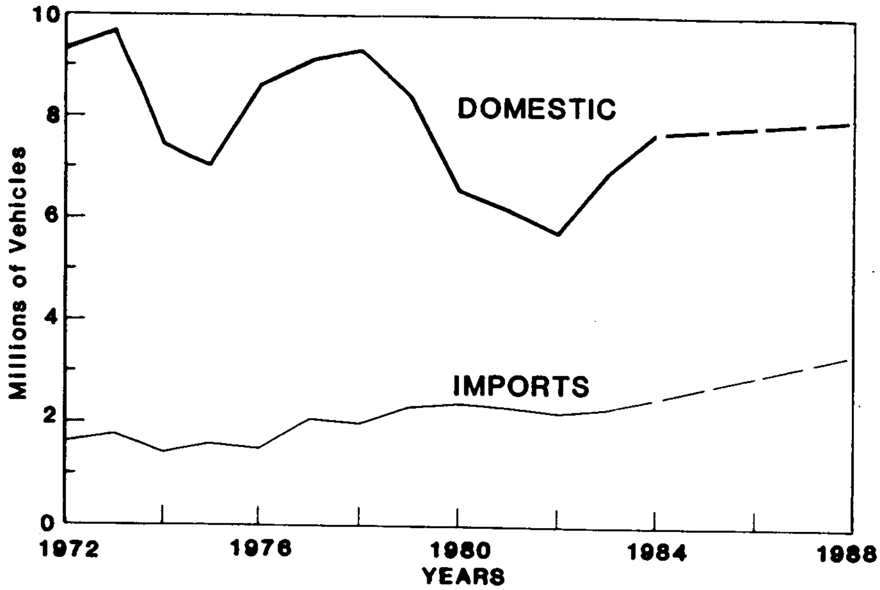
Quality indices of domestic versus foreign automobiles are shown in Table 2-12. In 1979, domestic automobiles were ranked inferior to foreign makes in terms of assembly quality or "fit and finish" as well as on ratings of body and mechanical repair frequency. As regards reliability, recalls resulting from safety related defects were considerably higher for domestic than for

TABLE 2-11

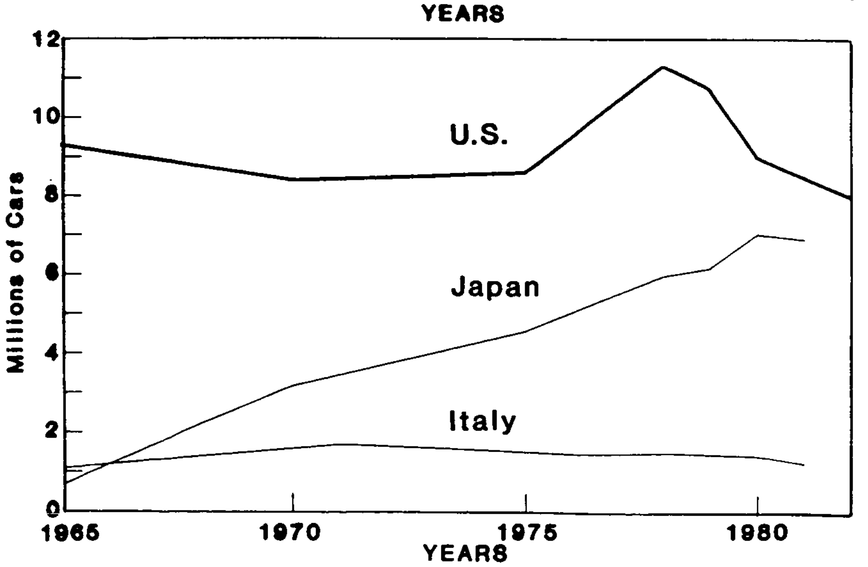
COMPETITIVE POSTURE OF THE
MOTOR VEHICLE INDUSTRY (SIC 371)

	1972	1977	1979	1981	1983	ANNUAL GROWTH RATE 1972-83
EXPORTS, BILLION CURRENT $	0.7	2.6	3.2	2.8	1.1	3.7%
IMPORTS, BILLION CURRENT $	3.5	7.6	12.7	15.9	18.4	16.4%

DOMESTIC AND IMPORT SALES



AUTOMOBILE PRODUCTION



SOURCES: U.S. DOC/BIE: 1984 U.S. INDUSTRIAL OUTLOOK
NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

TABLE 2-12

QUALITY INDICES OF MOTOR VEHICLES,
U.S. VERSUS IMPORTS, 1979

CONDITION OF CAR AT DELIVERY
(SCALE OF 1 - 10; 10 IS EXCELLENT)

TYPE OF CAR	DOMESTIC	IMPORTS
SUBCOMPACT	6.4	7.9
COMPACT	6.2	7.7
MIDSIZE	6.6	8.1
STANDARD	6.8	—

RATINGS OF BODY AND MECHANICAL REPAIR FREQUENCY, 1979
(20 = BEST; 10 = AVERAGE; 0 = WORST)

MAKE	BODY	MECHANICAL
BUICK	10	10
CHEVROLET	4	8
DODGE	8	8
FORD	9	7
LINCOLN	10	10
OLDSMOBILE	11	9
DATSUN	14	11
HONDA	16	12
MAZDA	18	13
TOYOTA	17	12
VOLKSWAGEN	14	11
VOLVO	16	11

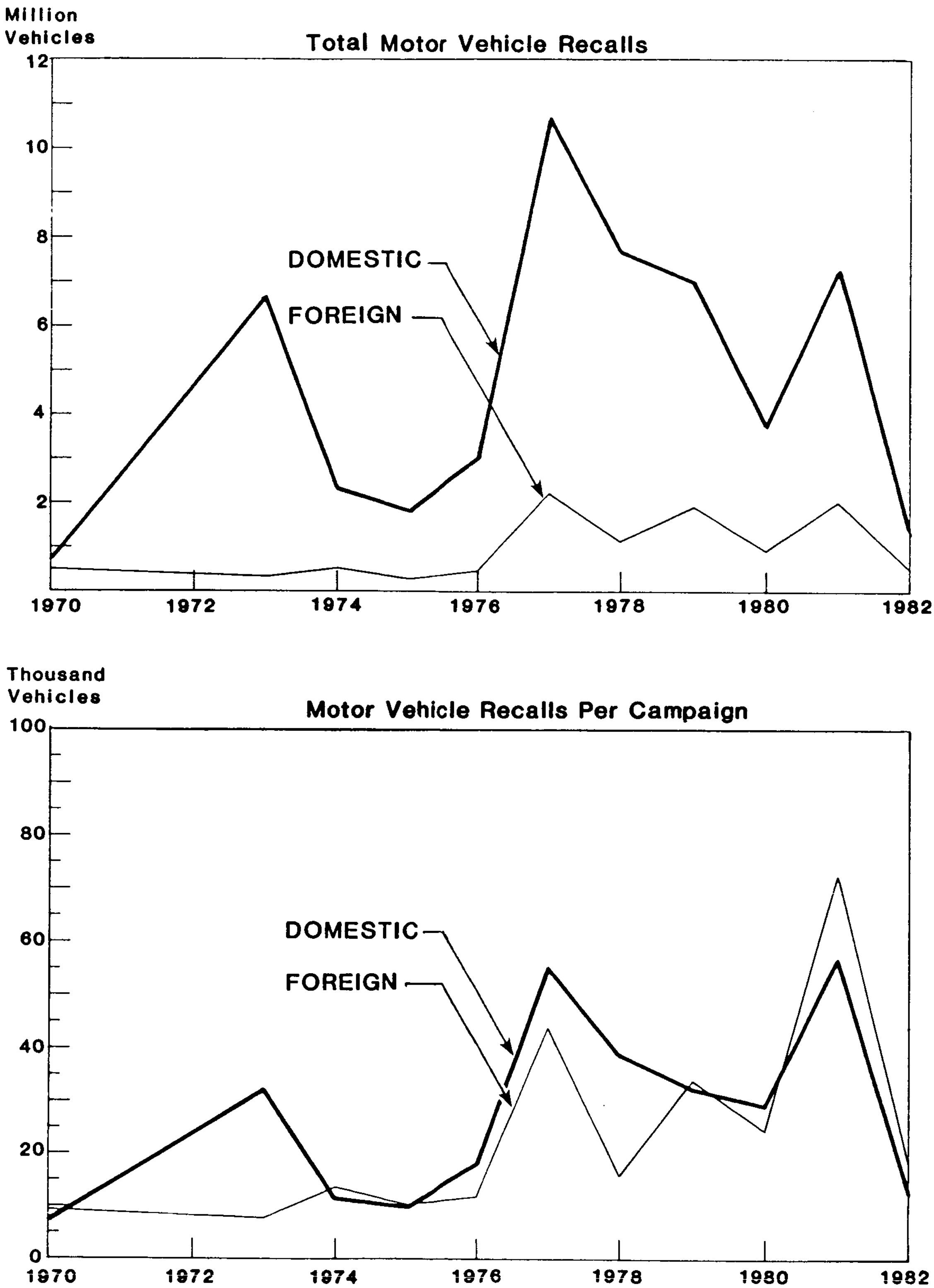
SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

foreign auto makers until 1979, Figure 2-12. Note, however that if the recall data are normalized to number of automobiles recalled per recall campaign (a recall campaign is the notification by a motor vehicle manufacturer of a safety defect to the Secretary of the U.S. Department of Transportation, owners, purchasers, and dealers), domestic automakers compare favorably with foreign makers. In recent years, 1979, 1981 and 1982, there have been more cars recalled per campaign by foreign automobile makers, e.g., 18,000 foreign versus 12,000 domestic in 1982. This would indicate that the quality trend is beginning to reverse.

The cost factor is intimately connected with the industry's productivity, as discussed below.

Productivity in the Motor Vehicle Industry

The data in Table 2-8, drawn from unpublished BLS data, show that labor productivity (output per employee hour) in the auto industry has been steadily growing over the last 15 years, except for temporary slowdowns, the last of which occurred in 1978. Currently, productivity shows a marked upswing. An important question is whether this productivity growth is sufficient to offset lower foreign labor costs. Figure 2-13 and Table 2-13 show the distribution of labor costs in the assembly of the typical automobile, exclusive of the production of input materials and parts. The Table also compares the productivity of typical U.S. and Japanese processes. It shows that total labor required in 1978 to manufacture a motor vehicle was 74 hours in the U.S. compared to only 39 hours in Japan. The largest difference, more than twofold, is in labor hours required for the assembly process. This has been attributed to differences in the sophistication of automation. Note that these labor costs apply only to automobile assemblage. Table 2-9 shows that approximately 75% of the average car's costs is in materials. See Figure 2-11 for detail. Implicit in the costs of these materials are additional labor costs.



Source: Calculated From U.S. Dept. Of Commerce, Bureau Of The Census Data

Figure 2-12. Motor Vehicle Safety Recalls

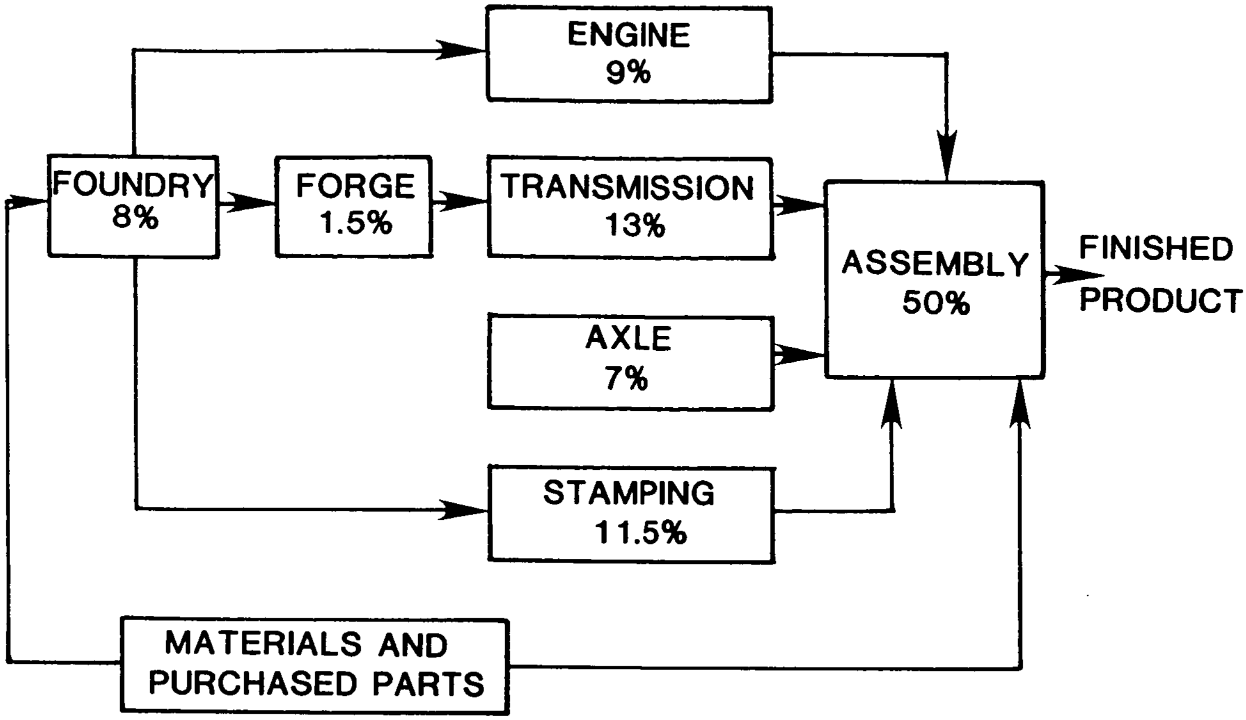


Figure 2-13. Average Manufacturing Labor Cost Distribution of Passenger Automobile Assemblage Process.

TABLE 2-13

LABOR REQUIREMENT FOR MOTOR VEHICLE ASSEMBLAGE: U.S. COMPARED TO JAPAN[a]

LABOR REQUIREMENTS
SELECTED PLANTS IN 1978

PROCESS	LABOR HOURS/VEHICLE U.S.	LABOR HOURS/VEHICLE JAPAN
ASSEMBLY	38	17
STAMPING	10	4
ENGINE	7	4
TRANSMISSION	8	6
AXLE	5	3
FOUNDRY	5	4
FORGE	1	1
TOTAL MANUFACTURE	74	39

[a] EXCLUSIVE OF MATERIALS AND INPUT PARTS

SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

Table 2-14 compares the cost and labor aggregates of Ford Motor Co. with those of Mazda Motor Corporation. In 1979 Mazda required 47 labor hours costing $491 to assemble a car; Ford needed 112 labor hours costing $2,464. These figures need to be tempered by the respective size mix of the cars; whereas Ford's production was largely in "standard" autos, Mazda's was overwhelmingly in compacts and subcompacts. Even when adjusted for this factor however, plus costs of oceanic transportation, the Japanese advantage in landed cost was still of order $1,000 per vehicle. The challenge is particularly severe because the average Japanese cost of labor ($10.50/hour including fringe benefits) was less than half the U.S. cost ($21.90/hour including benefits). On the surface, this means that, in order to remain competitive, U.S. labor productivity should increase by a factor of two to three. Note, however, that the cost advantage from increased labor productivity is small. This is because only 7% of the average car assemblage cost is manufacturing labor, see Table 2-9. Even if labor costs were reduced to zero, the cost savings on a $10,000 car would only be $700.

TABLE 2-14
COMPARATIVE LABOR/COSTS, FORD AND MAZDA, 1979

	FORD	MAZDA
PRODUCTION CARS AND TRUCKS (MILLIONS)	3.2	1.0
AUTOMOTIVE EMPLOYMENT (THOUSAND)	220	24
EMPLOYEE HOURS, AUTOMOTIVE (MILLIONS)	356	46
AUTOMOTIVE EMPLOYEE COST (MILLION $)	7794	482
EMPLOYEE HOURS/VEHICLE, UNCORRECTED	112	47
EMPLOYEE HOURS/VEHICLE, CORRECTED[a]	87	56
EMPLOYEE COST/VEHICLE, $, UNCORRECTED	2464	491
EMPLOYEE COST/VEHICLE, $, CORRECTED[a]	1893	589

[a] USING PRODUCT MIX/SIZE ADJUSTMENT

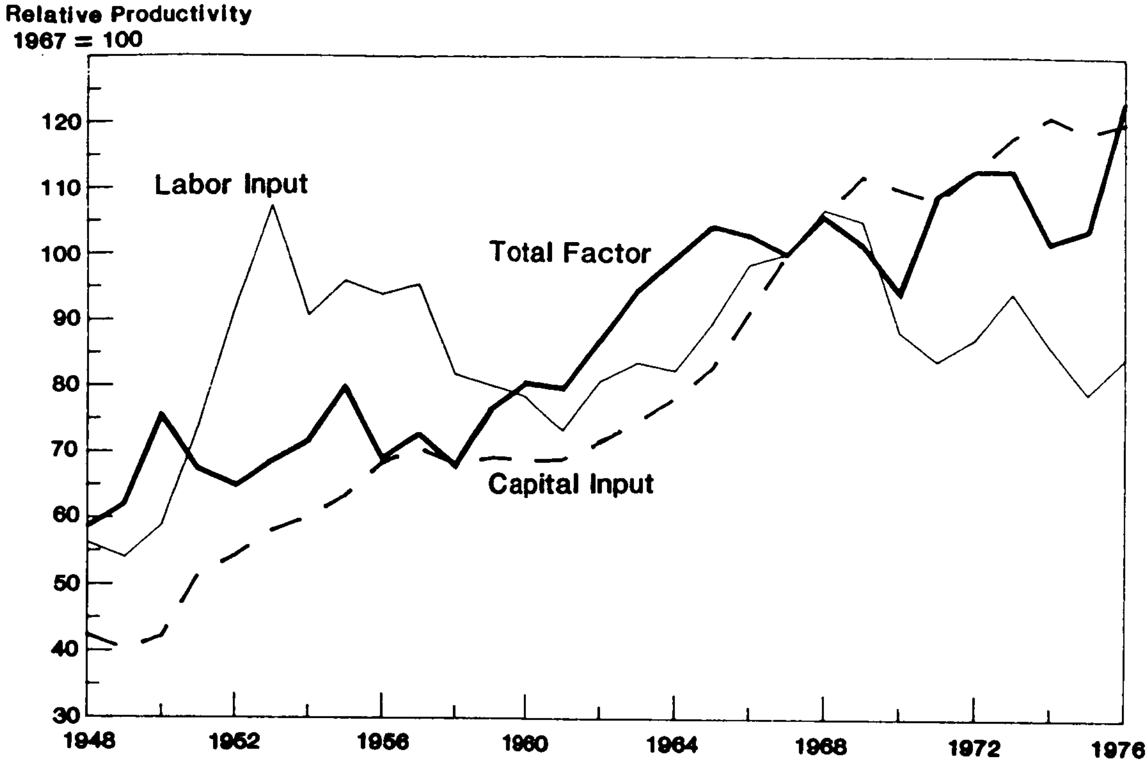
SOURCES: NATIONAL ACADEMY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

Capital productivity for the transportation equipment industry as a whole is shown in Figure 2-14. It can be seen that an investment of approximately one dollar is needed currently to produce a dollar of added value. Capital investment needs are growing: Investment per hour worked, expressed in 1972 dollars, has risen 2.6% per year in two decades from $8.26 in 1960 to $13.48 in 1979. The productivity of capital thus appears to be dwindling, despite the technological innovations of the last twenty years. Corresponding Japanese data are scarce, but all indications are that they are laboring under the same constraints. The major difference lies in the significantly lower costs of capital, see Figure 2-15.

This dwindling "margin of maneuver" of labor and capital portends the onset of an era in which the world's automotive industry will be faced with severe "dog eat dog" competition where the volume of sales will hinge upon small advantages, e.g., a few percentage points in price, somewhat better financing terms, marginal improvements in quality. The situation is typical of highly mature technologies. In this environment, how then can the U.S. auto industry meet the challenge? And to what extent does new technology play a role in the strategy?

Role of Technology in Long-term Strategic Outlook

In the early 1900s, when motor cars were few, France had the largest number of autos per capita. Since then, the U.S. has grown to lead all other nations both in the absolute number of registered motor vehicles and in the number of autos per capita. The U.S. leadership is even more pronounced when considering that most U.S. autos were, until recently, approximately twice to four times the size (by weight and engine capacity) of the average foreign car. However, except for significant improvements in efficiency, reliability and comfort, the basic technology of the automobile is not fundamentally different from eighty years ago.



Source: J.W. Kendrick

Figure 2-14. Productivity in Transportation Equipment

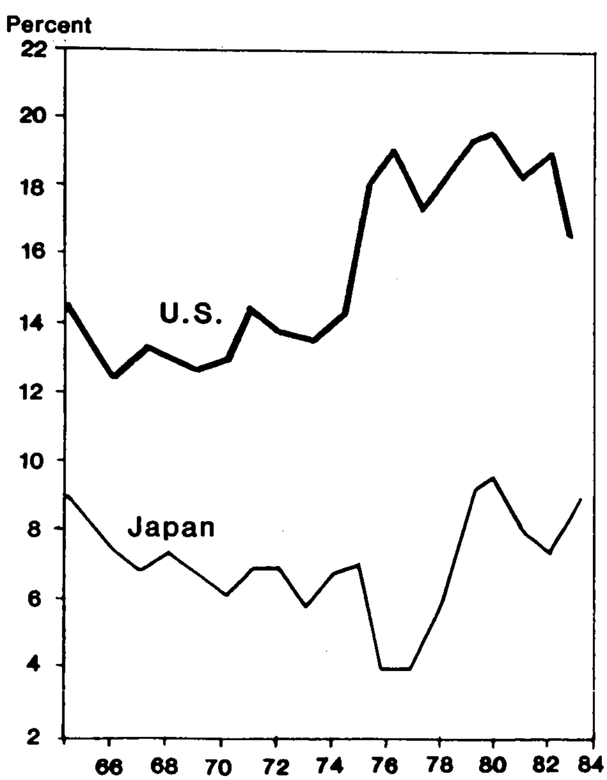


Figure 2-15. Relative Cost of Investment Capital, 1964 - 1983

Source: "High Cost Of Capital", 1983

Intuitively, the number of conventional autos in any given country or market area cannot grow indefinitely, but must be limited by some kind of saturation effect. Studies conducted in several developed countries appear to confirm this fact. Thus, important strategic questions are: How close are we now to saturation of the conventional auto market? And, how much room is left to grow for the conventional technology?

An imaginative approach to the question of saturation has been taken by Cesare Marchetti of the International Institute for Applied Systems Analysis Laxenberg, Austria. He shows that the historical trends of passenger motor vehicle registrations in all developed countries follow a logistic S-curve: A slow initial development is followed by a sustained increase which eventually flattens out. Following Marchetti, if the motor vehicle registration data are fitted to logistic curves of the type:

$$N = \frac{N_{sat} \quad ae^{-bt}}{1 + ae^{-bt}}$$

where: N = number of autos in a given country or region at time t

N_{sat} = saturation number of autos

t = time in years

a,b = coefficients peculiar to the country or region

a surprisingly good fit is observed, especially for the years following WWII. As an example, Figure 2-16 shows the fit of computed versus the actual passenger car registrations for the U.S. and Italy.

Figure 2-17 depicts the Marchetti automobile S-curves for the principal developed nations. As Marchetti points out, the exact reasons for the "S curve" behavior are imperfectly known. In particular, the saturation level appears to be weakly affected by population size, but to depend on region-specific factors as yet not fully understood.

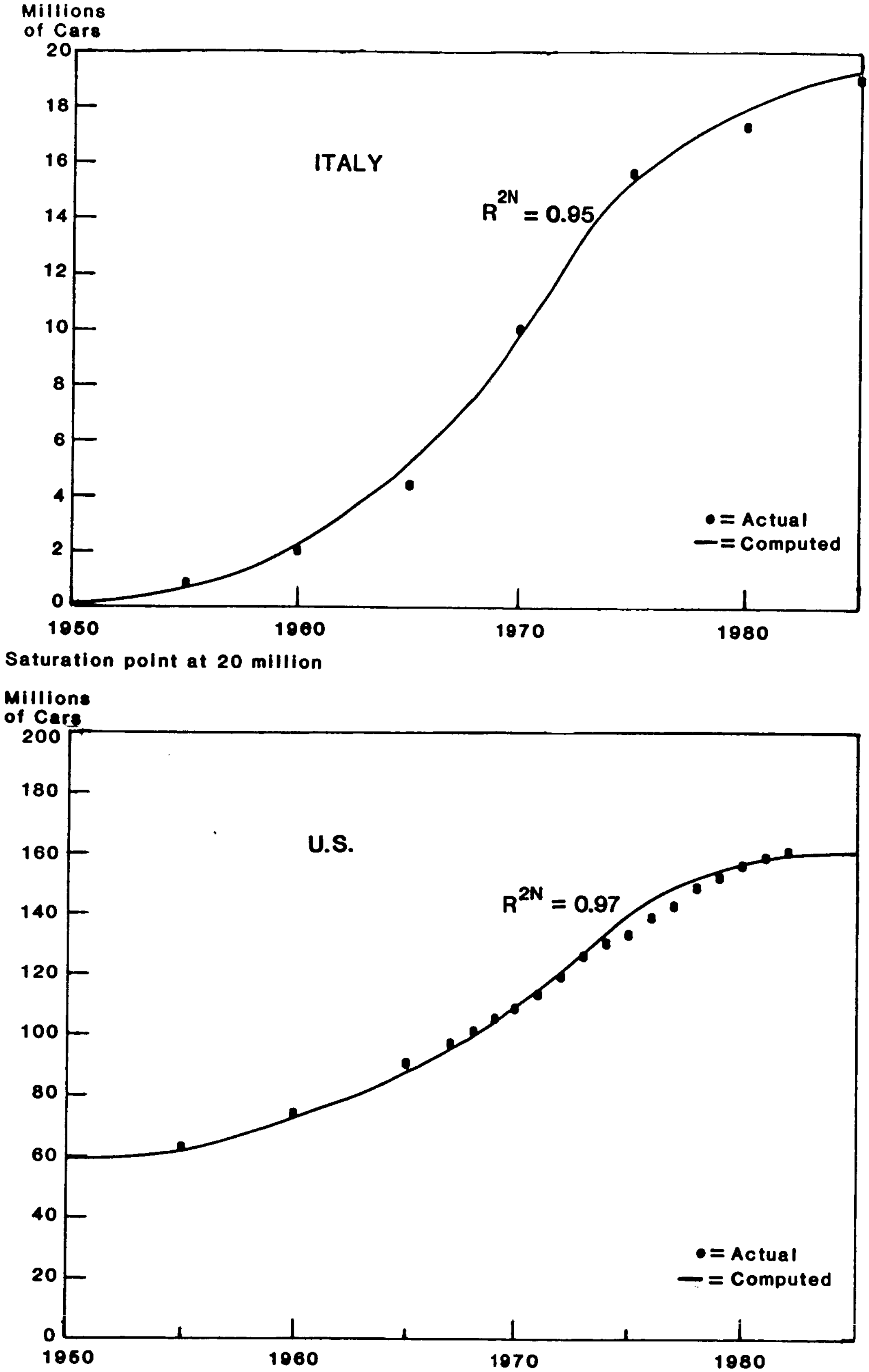


Figure 2-16. Historical Fit Between Car Registrations And Marchetti Logistic Curve

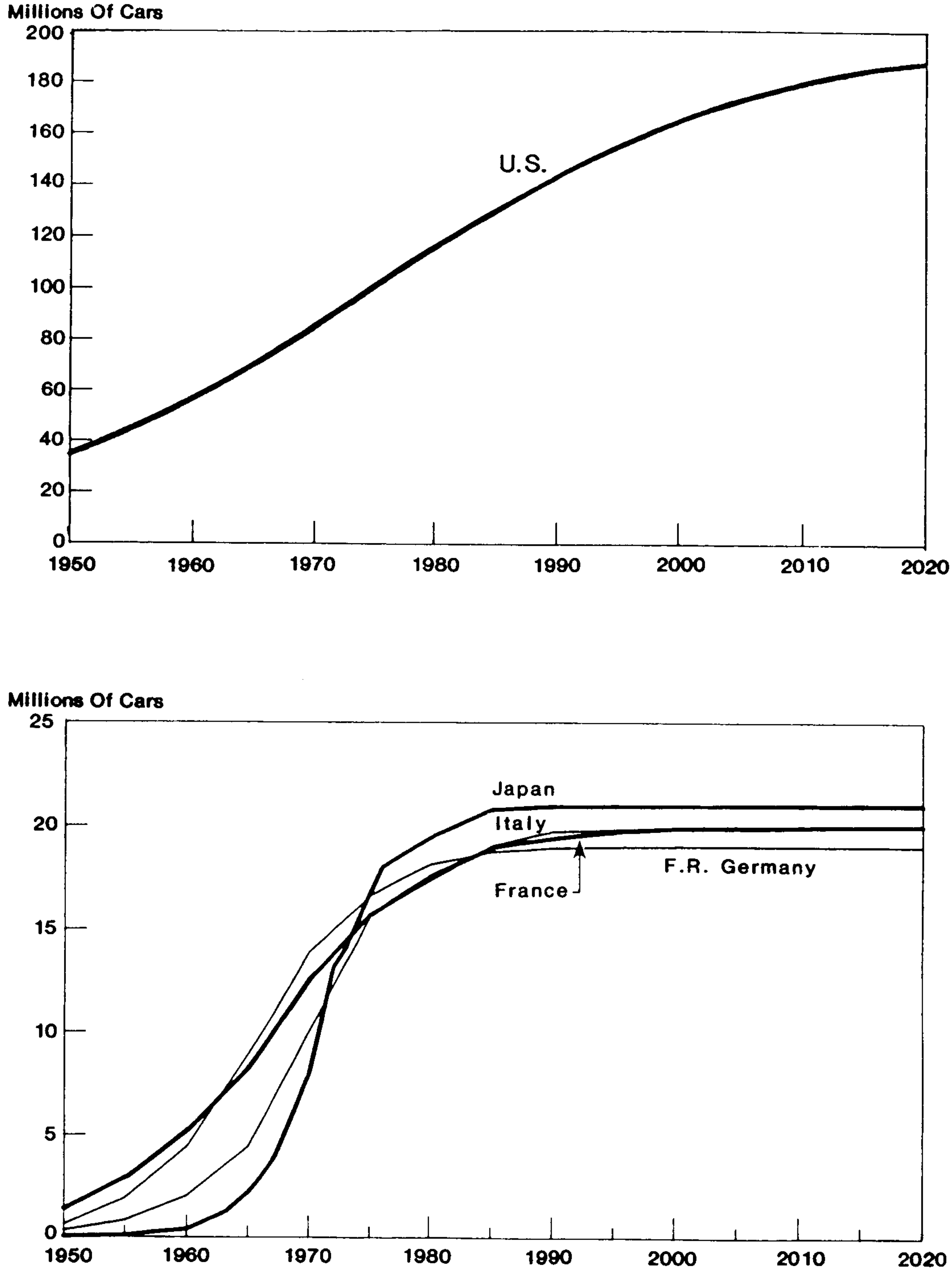


Figure 2-17. Car Registration for the U.S. and Selected Countries Marchetti Logistic Extrapolation

Figure 2-17 shows a trend towards saturation in all developed countries; while the U.S. appears to be saturating later, is on a path of ever-diminishing incremental growth.

What do these factors portend as regards the industry's strategic outlook? Two major points:

- The automotive demand in the developed economies appears to be heading towards a phase of saturation, in which the total auto market demand will be substantially "flat." In such a market, "new car" sales will predominantly be replacements for worn out or obsolescent vehicles.

- The significant potential expansion that appears to exist in third world markets is hampered by the poverty in these regions. Development of these regions requires investments to exploit local resources to generate the needed moneys. The risks, largely from political instabilities, have thus far severely hampered and curtailed such developments.

The "flat" market scenario indicates that the automotive industry, as presently structured, is neither "sunset" nor "sunrise;" rather, that its pattern of growth is substantially stationary. Significant expansion of the U.S. automotive industry, short of U.S.-foreign industry mergers, can only be achieved by displacing foreign manufacturers, both domestically and abroad. From what has been observed regarding U.S.-Japanese competition, this would entail significant reductions of cost and/or improvements in quality characteristics. In this connection, several points stand out:

- As observed earlier, the small residual margin currently available to labor productivity (approximately 7%) indicates that "labor-saving productivity" is not the smart way to go.

- While automation has been highly touted, it's introduction costs money. The dwindling productivity of capital during the last two decades indicates that this approach, albeit necessary in the near-term to maintain competitiveness, is not the innovative way to go.

- Thus technology, not labor and/or capital productivity, offers the hope to leapfrog the competition.

What technologies, then, are "coming down the pike" and what are the prospects that they can bring about a turn-around of the U.S. automotive industry? These questions are addressed following.

New Technologies in the Motor Vehicle Industry

Table 2-15 summarizes the new technologies currently being developed and planned by the industry. They fall into the following major groupings:

1. More efficient conventional propulsion. These are Internal Combustion Engines (ICE) using conventional hydrocarbon fuels more efficiently, or using nonconventional, domestically available hydrocarbon fuels such as gas, pulverized coal, fuels from renewable resources, e.g., alcohol. These technologies are essentially oriented to reducing operating costs.

2. Improved automotive subsystems, e.g., transmission; bodies with lower aerodynamic friction; internal energy and operations management subsystems, e.g., microprocessors. These technologies are oriented towards improved quality and somewhat reduced operating costs.

TABLE 2-15

NEW MOTOR VEHICLE TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	PRINCIPAL IMPACT	Approximate Era of Significant Diffusion			
			1985	1990	1995	2000
ICE—CONVENTIONAL FUELS						
• DIRECT INJECTED STRATIFIED CHARGE	FUEL INJECTION COMBINED WITH EVEN DISPERSION OF CHARGE	INCREASED FUEL EFFICIENCY				
• ADVANCED DIESEL (ADIABATIC TURBO COMPOUND)	COMBINATION OF DIESEL, TURBO-CHARGING AND TURBINES	INCREASED FUEL EFFICIENCY				
ICE—SPECIAL OR MULTIFUEL						
• TURBINE	AUTOMOTIVE ADAPTAION OF TURBINE TECHNOLOGY	INCREASED FUEL EFFICIENCY				
• STIRLING	AUTOMOTIVE USE OF MORE EFFICIENT STIRLING CYCLE ENGINE	INCREASED FUEL EFFICIENCY				
• METHANOL, GAS, COAL	NEW FUEL CAN BE USED IN CONVENTIONAL ENGINES	USE OF MORE ECONOMIC/AVAILABLE FUELS				
PRODUCTION TECHNIQUES						
• MODULAR CONSTRUCTION	USE OF "INTELLIGENT ROBOTS" IN MFG.	LOWER COST				
MECHANICAL AND MANAGEMENT SYSTEMS						
• CONTINUOUSLY VARIABLE TRANSMISSION	PULLEYS LINKED TO STEEL BELT—NO GEARS	INCREASED FUEL EFFICIENCY				
• NEW MATERIALS	STRUCTURAL PLASTICS, CERAMICS	DECREASED ENERGY DEMAND, LOWER COST				
• ELECTRONICS/COMPUTERS	OPTIMAL MANAGEMENTS OF CAR FUNCTIONS	INCREASED FUEL EFFICIENCY, CON-VENIENCE				
• HIGH PRESSURE TIRES	REDUCED ROLLING RESISTANCE	DECREASED FUEL DEMAND				
• DESIGN METHODS/MATERIALS FOR CRASHWORTHINESS	MORE CRASHWORTHY AUTOMOBILE	INCREASED SAFETY				
NEW PROPULSION METHODS						
• ELECTRIC	ELECTRIC BATTERY STORAGE AND ENGINE	ELIMINATES OIL FUEL				
• INERTIAL	FLY WHEEL ENERGY STORAGE	ELIMINATES OIL FUEL				
• FUEL CELL—ELECTRIC	CATALYTIC CONVERSION OF HYDROCARBON FUELS	MUCH INCREASED FUEL EFFICIENCY				
• HYBRID	COMBINATION OF NEW PROPULSION AND ICE	INCREASED FUEL EFFICIENCY				

3. Improved methods, techniques, technologies of manufacture. These are oriented primarily towards reduction of labor costs.

4. Novel types of propulsion. Principal among these:

   a. Conversion of the chemical energy of fuels into electrical energy at much higher efficiencies than available through ICE. The most representative device is the fuel cell.

   b. Energy storage devices capable of utilizing economical types of stationary energy to efficiently deliver mobile energy. Representative devices are inertia wheels, and electrical storage batteries.

Technology groups 1, 2, and 3 are essentially "more of the same" improvements to conventional technologies. The problem is that they are well-known to foreign competitors, who are also striving towards their development. Their introduction would not avoid an era of "dog eat dog" competition centering around a few percent price discounts and marginal (even if highly advertised) quality advantages, that would soon be caught up with by competition. In contrast, the group 4 technologies offer the possibility of dramatic breakthrough such as the development of the so-called "world car." Much discussed, notably in Japanese publications, salient characteristics of the world car would be low purchase cost, low operating cost, high reliability, and freedom from energy "surprises." Should U.S. industry be the first to develop this product, it would enjoy the immense advantage of the largest domestic market in the world. This would allow it to reach competitive status before other nations with more restricted domestic markets, see Figure 2-17. What new technological thrust could lead to the world car? Foremost is the development of practical mobile energy sources. The status and outlook for these is summarized in the following.

Mobile Energy Storage Technologies

Because of their high energy-to-weight-ratio, conventional hydrocarbon fuels are the prime sources of mobile energy. One kilogram of gasoline or diesel fuel contains approximately 12kWh of energy. Even at the low thermal efficiencies currently available from variable-speed, automotive Internal Combustion Engines (ICE), (average of order 20% over the speed range of 0-60 mph) this is still better than 2kWh/kg. Alternative energy sources which are most plentifully available to the U.S. (coal, nuclear) are not well-suited to mobile use, but to producing stationary energy. A similar restriction will apply to fusion energy, whenever it becomes available.

The U.S. electric utility industry currently produces 2.5 trillion kWh of stationary energy per year. The utilization factor is about 0.45. Utilization factor is the ratio of energy actually produced to the energy that could be generated by the existing plant. The utilization factor is low because the generating plant is sized to accommodate the peak energy demand, which lasts only for a fraction of the time. The demand drops at night, during weekends and other low demand periods. Thus a "latent" energy of approximately three trillion kWh/year is potentially available in the U.S. without significant modification to the existing plant. This is equivalent to the energy required to propel 160 million autos over approximately 300km (180 miles), every day, at 70km/h (40mph). Key to tapping this potential is the development of low-cost, low-weight storage devices.

Figure 2-18 shows typical power and energy requirements for a compact auto. Note that the energy consumed in overcoming grades can, in an electric vehicle, be largely recovered via dynamic braking.

Based on typical system efficiencies (of the order of 50 to 70%), the Figure shows that a 1,000kg (2,200lbs) auto, traveling at 100km/h (60mph), over a modern highway requires on the order of 12 to 15 kilowatts of output power from the storage device. A sustained 5-hour drive, covering 450km (280 miles) would thus require energy storage of the order of 60 to 75kWh.

To achieve a reasonable mass ratio of storage device to vehicle weight (about 10%) the energy storage density required is of order 1kWh/kg. This compares with 2kWh/kg for gasoline or diesel fuel, 0.05 to 0.1kWh/kg for conventional mobile storage batteries, 0.2kWh/kg for very advanced storage batteries.

Thus, the ability to realize the latent energy potential of stationary plants rests on development of energy storage only one order of magnitude beyond current technology.

Volume V, Section E.2, discusses the long-term research issues involved with development of improved storage devices and assesses the likelihood of realizing a "leapfrog" advance--with potential for dramatically changing the prospects of the auto industry.

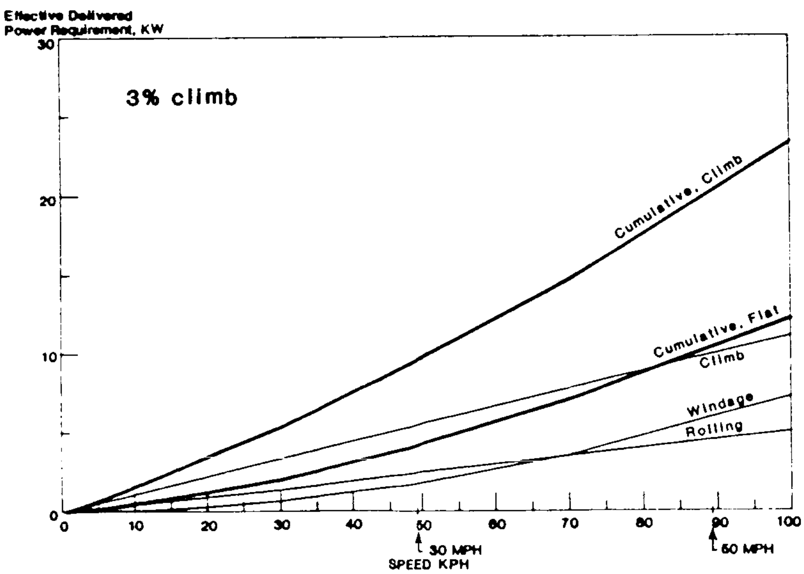


Figure 2-18. Output Power Requirements for a Typical Compact Auto, 1000kg Loaded Weight

2.4 SUMMARY OF ANALYSES OF TWENTY SIC SUBSECTORS

We conducted analyses similar to that described above for the auto industry for 19 other SIC subsectors, comprising approximately 45 subdivisions. Table 2-16 summarizes the results of the analysis.

As we did in Section 2.3 for SIC 37, Transportation Equipment Subsector, these analyses:

- Characterized each subsector and its major subdivisions in terms of their performance measures;
- Assessed their performance vis-a-vis foreign competition;
- Reviewed technology development programs currently underway;
- Identified requirements and opportunities for innovative technology advances that could induce leapfrog improvements in output, productivity quality, competitive position.

Integrating the findings shown in Table 2-16 with regard to the overall posture of U.S. industry, our analysis points to several key conclusions:

- None of the subsectors investigated is irretrievably "sunset." For most industry segments, opportunities exist for improving productivity, quality, competitiveness. Some segments of the industry however, can be expected to dwindle, outmoded by newer developments. An example is the passenger rail transportation subdivision of the transportation subsector, which has largely been replaced by the superior characteristics

Table 2-16.1

Summary Of SIC 35, Machinery Except Electrical 1983, 1972 $

1. SIC 35

Machinery Except Electrical

Establishments Engaged In

Manufacturing Machinery And Equipment, Except Electrical And Transporation.

Dominant Subdivisions

- Engines And Turbines
- Farm And Garden Machinery
- Construction, Mining, And Materials Handling Machinery
- Metalworking Machinery And Equipment
- Special Industry Machinery
- General Industry Machinery
- Office Computing, And Accounting Machines
- Refrigeration And Service Industry Machinery
- Miscellaneous Machinery

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector (%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	Labor Productivity: Dollar	Labor Productivity: Physical	Labor Productivity: Growth	Competitive[a] Labor Productivity: Dollar	Competitive[a] Labor Productivity: Physical	Competitive[a] Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
							0.72	23,117	1.26[b]	1.5%	13,124		5.2%		**Level Of R & D Expenditure** 3.3 Billion Dollars 2.7 % Of Industry Shipments
SIC 354 Machine Tool Industry Manufacture Of Powered Devices Including Robots, Woodworking Machines, And Specialized Tools And Dies.	13.7	297.8	10,628	22	0.4			21,895	1.11[b]					Sunset	**Thrusts Underway** • Numerical Control (NC) • Computerized NC (CNC) • Computer Aided Design (CAD) • Computer Aided Manufacture (CAM) • Computer Aided Engineering (CAE) • Flexible Manufacturing System (FMS) • Adaptive Machine Tool Controls (AMTC) • Metal Removal Technologies • Advanced Materials
SIC 357 Computing Machinery Industry Manufacture Of Computers, Typewriters, And Office Equipment	18.3	410.8	1,313	61	10.8	5.2		26,704	2.41[b]					Sunrise	**Thrusts Underway** • Vector, Pipeline, And Parallel Processing • Control And Data Driven Execution • GaAs And CMOS Circuits • Cryogenic Josephson Junctions • VLSI, VHSIC, And Wafer Scale Circuits • Integrated Optoelectronics
SIC 351 Engines And Turbines Industry Manufacture Of Steam, Water, And GasTurbines, And Also ICE's For Use In Heavy Machinery, Boats, And Tanks	6.6	85.3	316	34	0.8	1.4		29,211	1.06[b]					Saturated	**Thrusts Underway** • Computational Fluid Dynamics • Materials: Advanced Ceramics, Carbon-Matrix Composites, Advanced Metal Technology, Fluid Chromate Treatment • Manufacturing Systems: Spinforging, Flexible Manufacturing, Integrated Manufacturing

Table 2-16.2
Summary Of SIC 37, Transportation Equipment 1983, 1972 $

2. SIC 37
Transportation Equipment

Establishments Engaged In

Manufacturing Equipment For Transportation Of Passengers and Cargo By Land, Air And Water.

Dominant Subdivisions

- Motor Vehicles And Equipment, Aircraft And Parts
- Guided Missiles, Space Vehicles And Parts
- Ships And Boats
- Railroad Equipment
- Trailers, Tanks, etc.
- Motorcycles, Bicycles and Parts

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
							0.63	24,224	1.03[b]	0.6%	13,875		4.2%		**Level Of R & D Expenditure** 8.0 Billion Dollars 7.7 % Of Industry Shipments
SIC 371 Motor Vehicles & Equipment Manufacture Or Assembly Of Complete Automobiles, Trucks, Commercial Cars, Buses, Chassis, And Bodies	39.9	265.0	322	66	0.5	8.7		23,959	1.10[b]					Saturated	**Thrusts Underway** • Improved Efficiencies Conventional Engines (ICE) • Special Multifuel (ICE) • Improved Mechanical Subsystems • New Manufacturing Techniques (FMS, Robotics) • Novel Propulsion Types
SIC 372 Aircraft And Parts Manufacture, Research, And Developement Of Complete Military And Commercial Aircraft, Helicopters And Engines, Electronics, Components, And Auxiliary Equipment	36.1	689.7	1,280	91	8.0	1.9		26,646	1.16[b]					Sunrise	**Thrusts Underway** • Computational Aerodynamics • Laminar Flow Control Technology • New Materials Technology • New Propulsion Technology • Improved Avionics And Controls

Table 2-16.3
Summary Of SIC 36, Electrical Machinery And Components 1983, 1972 $

3. SIC 36 Electrical Machinery And Components	Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
Establishments Engaged In Manufacturing Machinery, Apparatus, And Supplies For The Generation, Storage, Transmission, Transformation, And Utilization Of Electrical Energy.								0.94	20,868	1.36[b]	1.6%	11,875		4.4%		Level Of R & D Expenditure 5.1 Billion Dollars 7.1 % Of Industry Shipments
Dominant Subdivisions • Communication Equipment • Electronic Components And Accessories • Electrical Industrial Apparatus • Electric Lighting And Wiring Equipment • Household Appliances • Miscellaneous Electrical Machinery, Equipment • Electrical Transmission And Distribution Equipment • Radio And TV Receiving Equipment, Except Communication Types	SIC 366 Communication Equipment Production Of Telephone And Telegraph Equipment, Radio And Television Broadcast Equipment, Communication Satellites, Mobile Radios, Radar, Search And Detection Equipment, And Electronic Mail Equipment	30.9	596.3	3,876	119	1.6	1.5		22,362	1.47[b]					Sunrise	Thrusts Underway • Electronic Switching Systems (ESS) • Transmission Innovations –Millimeter Waveguide –Fiber Optic Cables • Satellite Communications • Digital Transmission • Computer Application
Notes [a] "Competitive" Refers To Japan Unless Otherwise Indicated [b] Physical Output/Employee Hour In 1981: 1972 = 1.0	SIC 367 Electronic Components And Accessories Manufacturing Of Radio And Television Receiving Equipment, Electron Tubes, Semiconductors, Capacitors, Resistors, Coils, Connectors, And Miscellaneous Electrical Components	23.1	518.0	4,456	52	2.8	3.2		18,984	1.68[b]					Sunrise	Thrusts Underway • Computer Designed Semiconductors • Automated Assembly Lines • Numerically Controlled Machine Tools • Submicrostructural Sizes Of Semiconductors

Table 2-16.4

Summary Of SIC 20, Food And Kindred Products 1983, 1972 $

4. SIC 20

Food And Kindred Products

Establishments Engaged In

Manufacturing Or Processing Foods And Beverages For Human Consumption, And Related Products Including Ice, Chewing Gum, Vegetable Oils, Animal Fats, And Prepared Feeds For Animals And Fowls.

Dominant Subdivisions

- Beverages
- Meat Products
- Preserved Fruits And Vegetables
- Grain Mill Products
- Bakery Products
- Miscellaneous Food Products
- Dairy Products
- Sugar And Confectionary Products
- Fats And And Oils

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector (%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	Labor Productivity: Dollar	Labor Productivity: Physical	Labor Productivity: Growth	Competitive[a] Labor Productivity: Dollar	Competitive[a] Labor Productivity: Physical	Competitive[a] Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
All Subdivisions Manufacture Or Processing Of Beef, Pork, Poultry, Fish, Eggs, Butter, Cheese, Milk, Ice Cream, Canned, Dried, Pickled, And Frozen Fruits And Vegetables, Flour, Cereal, Rice, Corn, Pet Food, Poultry And Livestock Feed, Bread, Cookies, Crackers, Sugar, Chocolate, Chewing Gum, Cottonseed Oil, Soybean Oil, Vegetable Oil, Corn Oil, Animal And Marine Fats And Oils, Margarine, Malt Beverages, Wines, Distilled Liquor, Soft Drinks, Flavorings, Coffee, Ice, Pasta, Seasonings.	100.0	1569	26,656	99	30.0	9.5	0.93	27,496	1.22[b]	2.4%	10,955		4.8%	Saturated	**Level Of R & D Expenditure** 0.36 Billion Dollars 0.24 % Of Industry Shipments **Thrusts Underway** • Computer Control Processing • Removal Of Cholesterol, Salt, Fats • Ionizing Radiation Preservation • Synthetic Sweetners • Flavored Collagens • Artificial Food

Table 2-16.5
Summary Of SIC 34 Fabricated Metals 1983, 1972 $

5. SIC 34
Fabricated Metals

Establishments Engaged In

Fabricating Ferrous And Non-Ferrous Metal Products Such As Tinware, Metal Cans, Handtools, Cutery, General Hardware Non-Electric Heating Apparatus, Fabricated Structural Metal Products, Metal Forgings, Metal Stampings, And Other Metal Products.

Dominant Subdivisions

- Fabricated Structural Metal Products
- Miscellaneours Fabricated Metal Products
- Metal Forgings And Stampings
- Cutery, Handtools, And Hardware
- Metal Cans, Shipping Containers
- Screw Machine Products, Bolts
- Coatings And Engraving Services
- Ordance And Accessories
- Plumbing And Heating Exept Electrical

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 3441 Fabricated Structural Metals Industry							0.78	20,077	1.01[b]	1.3%	10,648		5.0%		Level R & D Expenditure: 0.31 Billion Dollars; 0.47 % Of Industry Shipments
Manufacture Of Fabricated Metal For Structures Such As Bridges, Buildings, And Sections Of Ships, Boats, And Barges	7.0	92.0	2,462	3	23.7	59.2		18,807	0.86[b]					Sunset	Thrusts Underway: • Beamline Technology • Welding: – Semi Automatic – Mechanized • Thermal Platecutting – Computer Numerical Control – Optical Trace Control – Cold Cutting Saw

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Table 2-16.6
Summary Of SIC 33, Primary Metals 1983, 1972 $

6. SIC 33
Primary Metals

Establishments Engaged In

Manufacturing Metals From Ore, Pig, Or Scrap: Manufacture Of Castings, Nails, Spikes, Insulated Wire And Cable, And The Production Of Coke.

Dominant Subdivisions

- Blast Furnaces, Steel Works, And Rolling And Finishing Mills
- Non-Ferrous Metals Produced By Rolling, Drawing, And Extruding
- Iron And Steel Foundaries
- Non-Ferrous Metals Produced By Smelting And Refining
- Non-Ferrous Metals Produced In Foundaries
- Miscellaneous Primary Metal Products
- Non-Ferrous Metals Produced By Secondary Refining

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	Labor Productivity[a]: Dollar	Labor Productivity[a]: Physical	Labor Productivity[a]: Growth	Competitive[a] Labor Productivity: Dollar	Competitive[a] Labor Productivity: Physical	Competitive[a] Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
							0.25	24,349	1.08[b]	2.3%	22,482		8.5%		Level Of R & D Expenditure 0.41 Billion Dollars 0.54 % Of Industry Shipments
SIC 331 Steel Industry Manufactures Unfinished, Processed, Or Raw Steel	46.9	330	1,165	83	0.4	3.6		25,556	1.10[b]					Sunset	Thrusts Underway • Continuous Casting • Electric-Arc Furnace • Computer Controls • Vacuum Degassing • Advanced Basic Oxygen Process (Q-Bop)

Table 2-16.7
Summary Of SIC 28, Chemicals And Allied Products 1983, 1972 $

7. SIC 28

Chemicals And Allied Products

<u>Establishments Engaged In</u>

Manufacturing (1) Basic Chemicals Such As Acids, Alkalines, Salts, And Organic Chemicals, (2) Chemical Products To Be Used In Further Manufacture Such As Synthetic Fibers, Plastics Materials, Dry Colors, And Pigments, (3) Finished Chemicals Such As Drugs, Cosmetics, And Soaps.

<u>Dominant Subdivisions</u>

- Industrial Organic Chemicals
- Drugs
- Soap, Cleaners, And Toilet Goods
- Plastics Materials And Synthetics
- Industrial Inorganic Chemicals
- Agricultural Chemicals
- Miscellaneous Chemical Products
- Paints And Allied Products

Notes

a "Competitive" Refers To Japan Unless Otherwise Indicated

b Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector (%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
							0.67	45,829	1.19[b]	1.9%	27,177		4.8%		Level Of R & D Expenditure 2.6 Billion Dollars 2.9 % Of Industry Shipments
SIC 282 Plastic Materials And Synthetics Manufacture Of Plastic Materials And Synthetic Resins, Synthetic Rubbers, And Cellulosic And Man-Made Organic Fibers.	13.3	131.3	636	43	1.3	0.3		35,468	1.62[b]					Sunrise	Thrusts Underway • L.P. Catalytic Polymerization • Interpenetrating Polymer Networks • Liquid Crystal Polymers • Intrinsically Conductive Polymers
SIC 283 Drugs Manufacture, Fabrication Or Processing Of Medicinal Chemicals And Pharmaceutical Products.	18.4	170.5	1243	36	1.2	0.6		43,704	1.18[b]					Sunrise	Thrusts Underway • Delivery Systems • Enzymatic Reactors • Immobilized Enzymes • Bio Process Engineering – Separation Processes – Sensors/Controls
SIC 286 Industrial Organic Chemicals Manufacture Of Industrial Organic Chemicals	20.1	134.5	879	32	2.5	1.2		53,289	1.07[b]					Saturated	Thrusts Underway • C_1 Chemistry • Zeolyte Catalysts • Enzymes • Separation
SIC 287 Agricultural Chemicals Manufacture Of Nitrogeneous And Phosphatic Basic Fertilizers, Mixed Fertilizers, Pesticides, And Other Agricultural Chemicals	7.7	47.1	1325	6	1.4	0.5		56,628	1.15[b]					Sunrise	Thrusts Underway • High Efficiency Ammonia Process • Biopesticides • Biofertilization • Allelopathy (Bioherbicides) • Coal Gasification

Table 2-16.8

Summary Of SIC 29, Petroleum Refining And Related Industries 1983,1972 $

8. SIC 29

Petroleum Refining And Related Industries

Establishments Engaged In Petroleum Refining, Manufacturing, Number Of Paving And Roofing Materials, And Compounding Lubricating Oils And Greases From Purchased Materials.

Dominant Subdivisions

- Petroleum Refining
- Paving And Roofing Materials
- Miscellaneous Petroleum And Coal Products

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators													Sunrise Sunset Assessment	Industry Technology Program
	Domestic										Competitive[a]				
	Contribution To Subsector(%)	Employees (1000)	Number Of Establishments		Exports Billions$	Imports Billions$	Capital Productivity	Labor Productivity			Labor Productivity				
			Total	>1000 Employees				Dollar	Physical	Growth	Dollar	Physical	Growth		
SIC 291 Petroleum Refining Processing Of Crude Petroleum And Natural Gas Liquid Products Into A Variety Of Primary Fuel Products							0.50	49,332	1.07[b]	2.2%	34,288		4.8%		Level Of R & D Expenditure 0.87 Billion Dollars 0.78 % Of Industry Shipments
	89.2	100.6	349	19	2.8	7.4		63,484	1.07[b]					Saturated	Thrusts Underway • Computer Controlled Refining • Catalyst Development • Energy Conservation Methods • Preventive Maintenance Technology • Multi-Fuel Capacity Plants

Table 2-16.9

Summary Of SIC 27, Printing And Publishing 1983,1972 $

9. SIC 27
Printing And Publishing

Establishments Engaged In

Printing Using Letterpress, Lithography, Gravure, Or Screen Process, And Those That Perform Bookbinding, Typesetting, Engraving, Photoengraving, And Electrotyping

Dominant Subdivisions

- Newspapers : Publishing & Printing,Commercial Printing
- Periodicals: Publishing & Printing
- Books
- Manifold Business Forms
- Printing Trade Services
- Miscellaneous Publishing
- Blankbook And Bookbinding
- Greeting Card Publishing

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	Labor Productivity: Dollar	Labor Productivity: Physical	Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Physical	Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 271 Newspaper Publishing And Printing							1.14	19,696	1.02[b]	0.4%	13,845		6.5%		Level Of R & D Expenditure N/A Billion Dollars N/A % Of Industry Shipments
Manufacture Of Daily, Sunday, And Weekly Newspapers	26.9	414.7	8,867	56	7.6	34.1		17,342	0.92[b]					Saturated	Thrusts Underway • Electronic Composition – Typesetting Computers – Video Display Terminals – Photo Typesetting • Data Transmission • Scanners – Optical Typesetting Scanners – Electronic Scanners • Web-Offset Printing • Binding Operations • Newspaper Mailroom
SIC 275 Commercial Printing Printing Of Advertising Matter, Periodicals, General Jobs, Financial Reports, Legal Data, Catalogs, And Directories	26.8	456.0	26,815	12	N/A	N/A		16,071	0.96[b]					Saturated	Thrusts Underway • Prepress – Increased Use Of Electronic Color – Electronic Pagination And Imposition Of Color – Several Options For Computer– To Plate For Color Printing • Printing – Closed Loop Sensing And Control For Color Printing – Potential Multi-Plant Printing Capability Via Electronic Or Satellite Communication • Assembly —More Complete Automation Via Electronic Sensing

Table 2-16. 10
Summary Of SIC 26, Paper And Allied Products 1983, 1972 $

10. SIC 26

Paper And Allied Products

Establishments Engaged In

Manufacturing Paperboard, Including Paperboard Coated On The Paperboard Machine, From Wood Pulp And Other Fibers

Dominant Subdivisions

- Converted Paper And Paperboard Products (Except Containers & Boxes)
- Papermills (Except Building Paper)
- Paperboard Containers And Boxes
- Paperboard Mills
- Pulp Mills
- Building Paper And Board Mills

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: $>$1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 264 Converted Paper And Paperboard Products Manufacture Of Adhesive Tape, Envelopes, Bags, Egg Cartons, Paper Plates, Facial Tissue, Stationary, And Wallpaper	34.3	218.3	2994	14	0.2	0.1	0.43	25,808 25,012	1.22[b] 1.06[b]	2.8%	12,459		5.0%	Saturated	Level Of R & D Expenditure 0.28 Billion Dollars 0.68 % Of Industry Shipments Thrusts Underway • Development Of Repulpable Tape • Automated Tape And Label Application • Computerized Label Imprinting Equipment
SIC 265 Paperboard Containers And Boxes Manufacture Of Folding Paperboard Boxes, Set Up Paperboard Boxes, Corrugated And Solid Fiber Boxes, Sanitary Food Containers, Fibercans, Tubes, And Drums	21.8	191.2	2860	6	0.1	0.01		18,024	1.21[b]					Saturated	Thrusts Underway • Improved Printing Processes • Radiation Ink Curing • Improved Equipment For Cutting And Creasing • Computer & Laser Methods To Prepare Dies • Automatic Stripping Of Waste • New Technology To Glue Cartons • Improved Packing Methods
SICS 261, 262, 263, 266, Pulp, Paper, And Board Mills Manufacture Of Pulp, Paper, Paperboard, And Paper Building Board From Wood Or Other Materials	43.9	202.6	691	52	1.6	2.3		32,489	1.19[b]					Saturated	Thrusts Underway • Mechanization Of Materials Handling • Improved Pulping Technology • Improved Papermaking Machines • Computer Control And Instrumentation • Pollution Control Technology

Table 2-16. 11

Summary Of SIC 38, Instruments And Related Products 1983, 1972 $

11. SIC 38 Instruments And Related Products	Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports $Billions	Domestic: Imports $Billions	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
Establishments Engaged In: Manufacturing Instruments Including Optical Instruments, Drafting And Surveying Instruments, Surgical, Medical, And Dental Instruments, Photographic Equipment, Watches, And Clocks	SIC 386 Photographic Equipment And Supplies Manufacture Of Photographic Apparatus, Parts, And Attachments, And Film	34.4	106.7	780	16	1.1	1.0	1.33	25,381	1.32[b]	1.0%	9,612		5.2%		Level Of R & D Expenditure 1.7 Billion Dollars 6.9 % Of Total Shipments
									48,826	1.42[b]					Saturated	Thrusts Underway Electronic Still Camera Electronic Imaging Color Film Printers Ink Jet Color Printers
Dominant Subdivisions • Engineering And Scientific Equipment • Measuring And Controlling Instruments • Optical Instruments And Lenses • Surgical, Medical, And Dental Instruments And Supplies • Opthalmic Goods • Photographic Equipment • Watches, Clocks, And Clockwork	SIC 384 Surgical, Medical, And Dental Instruments Manufacture Of All Types Of Surgical, Medical, And Dental Instruments And Supplies	18.0	141.2	2,353	14	N/A	N/A		20,225	1.11[b]					Sunrise	Thrusts Underway Curative Technology: Helium Beam Radiation, Coldfire Laser Surgery, Microwave Scalpel, Pump Apheresis, Endoscopics, Intra Artery Balloons, Computerized Anesthesiology New Materials Prosthesis: Artificial Organ Technology, Artificial Limb Prosthesis, Artificial Skin, Artificial Blood, Artificial Body Components, Neuromuscular Stimulators
Notes [a] "Competitive" Refers To Japan Unless Otherwise Indicated [b] Physical Output/Employee Hour In 1981: 1972 = 1.0	SIC 383 Optical Instruments And Lenses Manufacture Of Instruments That Measure Optical Property	4.6	45.5	546	4	N/A	N/A		23,438	1.80[b]					Sunrise	Thrusts Underway Lasers And Optic Fibers: Flat Panel TV Screens, Optic Fiber Thermometer, Long Lifespan Laser, Coherent Fiber Optic Technology, Integrated Optoelectronics Non-Invasive Diagnostics: Computer Axial Tomography, Nuclear Magnetic Resonance, Positron Emission Tomography(PET), Digital Substruction, Ultrasound Ultrasound Scanners(US)

Table 2-16.12
Summary Of SIC 32, Stone, Glass, And Clay 1983, 1972 $

12. SIC 32
Stone, Glass, and Clay

Establishments Engaged In

Manufacturing Flat Glass And Other Glass Products, Cement, Structural Clay Products, Pottery, Concrete And Gypsum Products, Ceramics, Cut Stone, And Asbestos Products From The Earth In The Form Of Stone, Clay, And Sand

Dominant Subdivisions

- Concrete, Gypsum, And Plaster Products
- Miscellaneous Non-Metallic Mineral Products
- Glass, Pressed Or Blown
- Cement, Hydraulic
- Products Of Purchased Glass
- Structural Clay Products
- Pottery And Related Products
- Flat Glass
- Cut Stone And Stone Products

Historical Perspective

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: > 1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
							0.47	21,979	1.05[b]	1.1%	12,897		5.8%		Level Of R & D Expenditure: 0.23 Billion Dollars; 0.88 % Of Industry Shipments
SIC 3271, 3272, 3273 Concrete Block, Concrete Products, And Ready Mix Concrete, In The Ready Mix State — Manufacture Of Concrete Building Block And Brick, Concrete Products And Portland Cement Concrete, In The Ready Mix State	29.9		10,627	N/A	7.8	8.5		21,340	0.98[b]					Saturated	Thrusts Underway: • Improved Material Handling Equipment • Improved Casting Methods Hot Concrete, Hot Oil, And Autoclave Curing Techniques • Automatic Batchers
Advanced Ceramics — Manufacture Of Advanced Ceramic Products Valued For Their Strength, Thermal, And Electrical Properties For Use In High Performance Engines, Machines, And Electronic Components	N/A	N/A	N/A	N/A	N/A	N/A		N/A	N/A					Sunrise	Thrusts Underway: • Electronic Applications – Capacitors – IC Packaging – Resistors – Sensors – Magnetic Components • Heat Engine Applications • Cutting Tool Applications • Wear Parts Applications

Table 2-16.13
Summary Of SIC 30, Rubber And Miscellaneous Plastics Products 1983, 1972 $

13. SIC 30
Rubber And Misc. Plastics Products

Establishments Engaged In

Manufacturing Rubber Products Such As Tires, Rubber Footwear, Mechanical Rubber Goods, Flooring, And In Molding Primary Plastics For The Trade And Manufacturing Of Miscellaneous Finished Plastics Products.

Dominant Subdivisions

- Miscellaneous Plastics Products
- Tires And Inner Tubes
- Other Fabricated Rubber Products
- Rubber And Plastics Hose And Belting
- Rubber And Plastics Footwear
- Reclaimed Rubber

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	Labor Productivity: Dollar	Labor Productivity: Physical	Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Physical	Competitive[a]: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 30							0.82	17,988	1.07[b]	- 0.6 %	11,508		4.4%		**Level Of R & D Expenditure** 0.37 Billion Dollars % Of Industry Shipments
SIC 307 Miscellaneous Plastics Products Manufacture Or Molding Of Fabricated Plastics Products Or Plastics Film, Sheet, Rod, Non-textile Monofila ments, Regenerated Cellulose Products, And Vulcanized Fiber	64.4	452.2	10,122	17	0.9	0.5		17,332	1.12[b]					Saturated	**Thrusts Underway** • Resin Transfer Molding • Twin Screw Extrusion And Compounding • Reaction Injection Molding (RIM) • Sheet Molding Compound (SMC) • Pultrusion • Thermoforming • Sheet And Film Co-Extrusion And Lamination • Injection Blow-Molding And Co-Extrusion Blow-Molding

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Physical Output/Employee Hour In 1981: 1972 = 1.0

Table 2-16.14
Summary Of SICs 50-59, Wholesale And Retail Trade 1983, 1972 $

14. SICs 50-59 Wholesale And Retail Trade	Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports	Domestic: Imports	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
Establishments Engaged In Selling Merchandise To Industry, Commercial, Institutional, Farm, Or Professional Business Users, And To Personal And Household Users.	SIC 514 Groceries And Related Products Purchase Of Foodstuffs From Growers, Processors, And Manufacturers And Distribution To Grocery Stores, Restaurants, Hospitals, Schools, And Other Institutions								12,050	N/A	0.2%					Level Of R & D Expenditure Billion Dollars % Of Gross Assets
		29.8	452.1	29,267	N/A	*	*		N/A	N/A					Saturated	Thrusts Underway • Coding Of Inventory • Computerization • Automated Warehousing
Dominant Subdivisions • Motor Vehicles And Supplies • Furniture And Home Furnishings • Lumber And Construction Materials • Sporting, Recreational, & Photographic Goods • Metals And Minerals • Electrical Goods • Hardware And Plumbing Goods • Machinery, Equipment, & Supplies • Misc. Durable Goods • Paper And Paper Products • Drugs • Apparel • Groceries • Farm Produced Raw Materials • Chemicals And Allied Products • Petroleum And Related Products • Beer, Wine, And Distilled Beverages • Misc. Non-Durable Goods • Eating And Drinking Places	SIC 54 Food Stores Retail Sale Of All Types Of Food And Food Products And Related Items	21.8	2,500	N/A	*	*	*		N/A	0.91[b]					Saturated	Level Of R & D Expenditure Billion Dollars % Of Gross Assets Thrusts Underway • Computerized Cash Registers • Microfilming • ATM,S And EFT,S • Videodiscs And CATV

Notes

[a] "Competitive" Refers To Japan Unless Otherwise Indicated

[b] Square Foot/Worker In 1981 : 1972 = 1.0

Table 2-16.15
Summary Of SICs 90-97, Government And Government Enterprise 1983, 1972 $

15. SICs 90-97 Government And Government Enterprises	Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports	Imports	Capital Productivity	Labor Productivity: Dollar	Labor Productivity: Physical	Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
Establishments Engaged In Government Including Legislative, Judicial, Administrative, And Regulatory Activities Of Federal, State, and Local Governments	**Education** Includes Institutions Devoted To Furnishing Formal Academic Or Technical Courses								33,190		-0.3%					**Level Of R & D Expenditure** N/A Billion Dollars N/A % Of Gross Assets
Dominant Subdivisions • Insurance Trust • Education • National Defense • Public Welfare • Interest On General Debt • Health Care • Highways • Natural Resources		16.1	2,000.0	144,836	N/A	*	*			N/A					Saturated	**Thrusts Underway** • Artificial Intelligence • Education Stations, Displays • Communications • Behavior Modification • Neurophysiology
Historical Perspective																

Table 2-16. 16
Summary Of SICs 60-67, Finance, Insurance, And Real Estate 1983, 1972 $

16. SICs 60-67
Finance, Insurance & Real Estate

Establishments Engaged In

The Fields Of Finance, Insurance, And Real Estate.

Dominant Subdivisions

- Commercial And Stock Savings Banks
- Savings And Loan Associations
- Personal And Business Credit Institutions
- Federal Reserve Banks
- Mutual Savings Bonds

Historical Perspective

Subdivisions Analyzed	Domestic: Contribution To Subsector (%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 602 Commercial And Stock Savings Banks							N/A	39,696	N/A	0.1%					Level Of R&D Expenditure N/A Billion Dollars N/A % Of Gross Assets
Accept Deposits From The Public, Loan Funds To Public And Private Sector.	57.5	153.0	39,532	N/A	N/A	N/A		N/A	1.00[b]					Saturated	Thrusts Underway • In Home Information • Electronic Funds Transfer (EFT)
SIC 612 Savings And Loan Industry Accept Deposits From The Public, Primarily Loan Funds To Home Mortgage Market.	21.6	295.0	N/A	N/A	N/A	N/A		N/A	N/A					Saturated	Thrusts Underway • In-Home Information • Electronic Funds Transfer

Table 2-16. 17
Summary Of SICs 41, 42, 44-47 Transportation Services 1983, 1972 $

17. SICs 41, 42, 44-47
Transportation Services

Establishments Engaged In

Passenger Transportation To The General Public, And Freight Transportation.

Dominant Subdivisions

- Railroad Transportation
- Local And Suburban Highway Passenger Transportation
- Motor Freight Transportation And Warehousing
- Water Transportation
- Air Transportation
- Pipelines (Except Natural Gas)
- Transportation Services

Historical Perspective

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	★ Labor Productivity: Dollar	★ Labor Productivity: Physical	★ Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 401 Line-Haul Operating Railroads Operation Of Line-Haul Railroads							N/A	21,578	N/A	1.9%					**Level Of R&D Expenditure** N/A Billion Dollars N/A % Of Gross Assets
	N/A	398.0	329	N/A	*	*		N/A	1.27^b					Sunset	**Thrusts Underway** • Motive Power Developements • Freight Car Improvements • Piggyback & Unit Trains • Automatic Classification Yards • Centralized Traffic Control • Signaling And Communications • Maintainance Of Way Innovations
SIC 42 Intercity Trucking Furnishing Long Distance Or Local Trucking	60	115.0	N/A	N/A				N/A	N/A					Saturated	**Level Of R&D Expenditure** N/A Billion Dollars N/A % Of Gross Assets **Thrusts Underway** • Greater Trailor Capacity • Diesel Powered Engines • Lighter Truck Body And Tires • Computer Applications
SIC 45 Air Transportation Furnish Domestic And Foreign Transportation By Air	11	330.0	95	N/A	*	*		N/A	N/A					Sunrise	**Level Of R&D Expenditures** N/A Billion Dollars N/A % Of Gross Assets **Thrusts Underway** • More Efficient Airframes And Engines • Navigational Advances • Surveillance And Collision Control • Developements In Traffic Flow • Automated Airport Terminals
SIC 44 Water Transportation Supply Freight And Passenger Transportation On The Open Seas Or On Inland Water	5	N/A	N/A	N/A				N/A	N/A					Saturated	**Level Of R&D Expenditures** N/A Billion Dollars N/A % Of Gross Assets **Thrusts Underway** • Cargo Containerization • Increased Cargo Capacity • Centralized Engine Controls • Bow Thrusts • Improved Marine Coatings • Vessel Traffic Management System • Performance Monitoring Systems • Global Positioning System

★ Labor Productivity Is For Transportation & Communication Services Combined.

Table 2-16.18
Summary Of SIC 48, Communication Services 1983, 1972 $

18. SIC 48
Communication Services

Establishments Engaged In
Providing The Transfer Of Information Between Individuals, Directly Or Through The Intermediary Of Mechanical, Electrical, Or Electronic Machinery

Dominant Subdivisions
- Telephone Communications
- Telegraph Communications
- Radio And Television Broadcasting
- Other Communications Services

Notes

a "Competitive" Refers To Japan Unless Otherwise Indicated

b Physical Output/Employee Hour In 1981: 1972 = 1.0

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Employees (1000)	Number Of Establishments: Total	Number Of Establishments: >1000 Employees	Exports Billions$	Imports Billions$	Capital Productivity	★Labor Productivity: Dollar	★Labor Productivity: Physical	★Labor Productivity: Growth	Competitive[a] Labor Productivity: Dollar	Competitive[a] Labor Productivity: Physical	Competitive[a] Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 481 Telephone Communications Furnish Telephone Communication Service By Placing The Parties In Vocal Contact With Each Other	80.5	112.0	N/A	N/A	*	*	N/A	21,578	1.77[b]	1.9%				Sunrise	**Level Of R&D Expenditure** N/A Billion Dollars; N/A % Of Gross Assets. **Thrusts Underway** • Satellite Communications • Fiber Optics • Cellular Mobile Telephone • Electronic Switching System

★ Labor Productivity Is For Transportation And Communication Services Combined

Table 2-16. 19
Summary Of SICs 15, 16, 17 Construction 1983, 1972 $

19. SICs 15, 16, 17
Construction

Establishments Engaged In

Building Construction, Non-Building Construction , And Special Trade Contracts

Dominant Subdivisions

- Residential Building Contractors
- Operative Builders
- Non-Residential Building Contractors
- Highway And Street Construction
- Heavy Construction
- Plumbing, Heating, And Air Conditioning
- Painting, Paper Hanging, And Decorating
- Electrical Work
- Masonry And Stonework
- Carpentry And Flooring
- Roofing And Sheetmetal Work
- Concrete Work
- Water Well Drilling
- Misc. Special Contractors

Historical Perspective

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector (%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
Construction Residential Construction Of Residential Buildings	41.2	330.0	443,641	41	*	*	N/A	23,173	808[b]	-2.24%		623[b]		Saturated	**Level Of R&D Expenditure** N/A Billion Dollars % Of Gross Assets **Thrusts Underway** • Computer Aided Design (CAD) • Computer Aided Manufacture (CAM) • New Materials
Non-Residential Building Construction Construction Of Farm, Commercial, Industrial, Or Other Builders	36.2	N/A	N/A	N/A	*	*								Saturated	**Level Of R&D Expenditure** N/A Billion Dollars N/A % Of Gross Assets **Thrusts Underway** • Computer Aided Design (CAD) • Computer Aided Manufacture (CAM) • New Materials

Table 2-16. 20
Summary Of SICs 10-14, Mining 1983, 1972 $

20. SICs 10-14
Mining

Establishments Engaged In
Extraction Of Minerals Occurring Naturally Such As Coal, Ore, Liquids, Stone, And Gases

Dominant Subdivisions
- Metal Mining
- Anthracite Mining
- Bituminous Coal And Lignite Mining
- Oil And Gas Extractions
- Mining And Quarrying Of Non-Metallic Minerals Except Fuels

Historical Perspective

Subdivisions Analyzed	Performance Indicators: Domestic: Contribution To Subsector(%)	Domestic: Employees (1000)	Domestic: Number Of Establishments: Total	Domestic: Number Of Establishments: >1000 Employees	Domestic: Exports Billions$	Domestic: Imports Billions$	Domestic: Capital Productivity	Domestic: Labor Productivity: Dollar	Domestic: Labor Productivity: Physical	Domestic: Labor Productivity: Growth	Competitive[a]: Labor Productivity: Dollar	Competitive[a]: Labor Productivity: Physical	Competitive[a]: Labor Productivity: Growth	Sunrise Sunset Assessment	Industry Technology Program
SIC 13 Petroleum Extraction Of Petroleum, Natural Gas, And Petroleum Products From The Ground	60.3	199.9	17,755	23	0.8	50.6	N/A	N/A	N/A	N/A				Saturated	**Level Of R&D Expenditures** N/A Billion Dollars; N/A % Of Gross Assets. **Thrusts Underway** • Tertiary Methods Of Oil Extraction • Oil Production From Alternative Sources • Alternative Methods Of Natural Gas Extraction
SIC 11, 12 Coal Mining Mining Of Anthracite Coal And Bituminous Coal From The Ground	24.9	217.1	5,451	3	5.9	*		N/A	N/A					Saturated	**Thrusts Underway** • Improvements In Surface Mining • Longwall Mining Systems • Continuous Miners & Slurry Pipelines • Use Of Computers • Teleoperator

of air transportation technology. Still newer technologies, such as "live presence communications,"--i.e. the ability to use enhanced communications facilities for teleconferencing--may accelerate this process, and may even impact the demand for passenger transportation across the board.

- Several industry segments show significant opportunities for "sunrise" growth. Examples include voice and high speed data communications, and the plastics segment of the chemical and allied subsector.

- In the future, the manufacturing sector will be characterized by higher labor productivities. This will significantly change the character of the sector. Total manufacturing labor force will dwindle, and its skill level will rise. The production worker in 2010 will require a semi-professional background, much as the modern farmer needs to have a far broader understanding of agribusiness than he did 20 years ago. A similar emphasis on professional know-how will apply to the growing labor force in the service industries.

With regard to industrial technological issues and opportunities, the analysis points to the following:

- The R&D horizons of U.S. industry are limited by the economic necessity of achieving adequate returns on investments. In the 20 subsectors we investigated, advanced technology programs show a time frame of 3 to 10 years. Almost none extends to 2005-2010.

- The technology programs currently being pursued by industry encompass most of the advanced technologies foreseeable for 2005-2010. When tested against each industry's competitive requirements, we encountered little need to "invent" technologies not foreshadowed in one or more current industrial programs. However, for reasons of cost and pressing need to achieve early returns on the R&D moneys invested, industrial programs do not push the identified technologies to their ultimate capabilities.

Thus, none of the approximately 180 technology programs underway in the 20 industrial subsectors and 45 subdivisions we reviewed would, in principle, qualify as a long-term technology initiative, as defined in this study. To identify these initiatives, we proceeded in the following manner:

- For each of the 180 industrial technology programs identified, we initially assessed whether the program's goals, as established by industry, would lead to major improvements of that industry's productivity and competitiveness. We designated such improvements as "hemibel enhancements," i.e., approximating at least one half order of magnitude (factor of 3 or better).

  As an example of a less than hemibel improvement, the technology program for improving mechanical subsystems, currently pursued by the motor vehicle industry, SIC 371--although needed in the near-term to match foreign competition--does not portend increments in ultimate automotive performance exceeding 20-30%.

- We next investigated whether significant improvements were possible by pushing each of the identified technology programs to its logical limit. Initially we assessed whether basic physical laws limit each technology's ultimate performance.

  For example, the automotive industry's technology program for improving the efficiency of internal combustion engines is ultimately limited by Carnot cycle constraints to approximately twice the current performance, placing this particular technology program on the threshold, but not quite within, a hemibel improvement.

- We identified as leapfrog candidates those technologies whose ultimate physical limitations exceeded the hemibel criterion. For each, we investigated: 1) the basic needs of the program, i.e., what underlying technological advances would most contribute to the program's success: and 2) whether the technology program's fruition could reasonably be expected to occur by 2005-2010.

For example, the automotive industry's technology program on new types of propulsion could not be expected to lead to hemibel improvements using conventional hydrocarbon fuels, because their energy content is constrained by an upper limit. Potential alternative technologies include portable fusion and mobile energy storage. We judge that attainment of the former lies beyond the 2005-2010 time frame. As regards the latter, we found that the single major requirement is the achievement of energy storage media capable of energy densities of order 1kWh/kg. Since the previous step of our analysis--limitations by laws of nature--had indicated that the ultimate physical limit lies above 6kWh/kg, and because the impediments to attainment of this technology appear to be primarily of an engineering (rather than of a basic nature), we selected mobile energy storage as candidate for one of the leapfrog technology thrusts.

Table 2-17 summarizes our analysis.

2.5 PERVASIVE TECHNOLOGIES

We found that the R&D thrusts of the industries surveyed are not as disparate as they seem to appear in Table 2-16. In fact, we were able to identify several "pervasive" technologies that

TABLE 2-17
ASSESSMENT OF UNDERLYING CORE TECHNOLOGICAL ELEMENTS

SUBSECTOR	SUBDIVISION	INDUSTRY TECHNOLOGY PROGRAM	ASSESSMENT CRITERIA: HEMIBEL AS APPROACHED?	ASSESSMENT CRITERIA: HEMIBEL FEASIBLE?	KEY TECHNOLOGICAL ELEMENTS	FRUITION BY 2010
MACHINERY EXCEPT ELECTRICAL (SIC 35)	MACHINE TOOL INDUSTRY (SIC 354)	NUMERICAL CONTROL (NC)	-	-	—	—
		COMPUTERIZED NC (CNC)	-	-	—	—
		COMPUTER-AIDED DESIGN (CAD)	-	•	AI	•
		COMPUTER-AIDED MANUFACTURE (CAM)	-	•	AI, PATTERN RECOGNITION	•
		COMPUTER-AIDED ENGINEERING (CAE)	-	-	—	—
		FLEXIBLE MANUFACTURING SYSTEM (FMS)	-	•	AI, PATTERN RECOGNITION	•
		ADAPTIVE MACHINE TOOL CONTROLS (AMTC)	-	-	—	—
		METAL REMOVAL TECHNOLOGIES	-	-	—	—
		ADVANCED MATERIALS	-	•	ADVANCED MATERIALS, CUSTOM MULTIPROPERTY MATERIALS	•
	COMPUTING MACHINERY INDUSTRY (SIC 357)	VECTOR, PIPELINE, AND PARALLEL PROCESSING	-	•	AI	•
		CONTROL AND DATA DRIVEN EXECUTION	-	•	AI	•
		GAAS AND CMOS CIRCUITS	-	•	ADVANCED MATERIALS	•
		CRYROGENIC JOSEPHSON JUNCTIONS	-	•	ADVANCED MATERIALS	•
		VLSI, VHSIC, AND WAFER SCALE CIRCUITS	-	•	ADVANCED MATERIALS	•
		INTEGRATED OPTOELECTRONICS	-	•	ADVANCED MATERIALS	•
	ENGINES AND TURBINES INDUSTRY (SIC 351)	COMPUTATIONAL FLUID DYNAMICS	-	-	—	—
		ADVANCED MATERIALS	-	•	ADVANCED MATERIALS	•
		FLEXIBLE MANUFACTURING SYSTEMS	-	•	AI, PATTERN RECOGNITION	•
TRANSPORTATION EQUIPMENT (SIC 37)	MOTOR VEHICLES AND EQUIPMENT (SIC 371)	IMPROVED EFFICIENCY CONVENTIONAL ENGINES (ICE)	-	-	—	—
		SPECIAL MULTIFUEL (ICE)	-	-	—	—
		IMPROVED MECHANICAL SUBSYSTEMS	-	-	—	—
		NEW MANUFACTURING TECHNIQUES (FMS, ROBOTICS)	-	•	AI, PATTERN RECOGNITION	—
		NOVEL PROPULSION TYPES	-	•	MOBILE ENERGY STORAGE	•
			-	•	PORTABLE FUSION	—
	AIRCRAFT AND PARTS (SIC 372)	COMPUTATIONAL AERODYNAMICS	-	-	—	—
		LAMINAR FLOW CONTROL TECHNOLOGY	-	-	—	—
		NEW MATERIALS TECHNOLOGY	-	•	ADVANCED MATERIALS	-
					CUSTOM MULTIPROPERTY MATERIALS	-
		NEW PROPULSION TECHNOLOGY	-	•	PORTABLE FUSION	-
			-	•	MOBILE ENERGY STORAGE	-
		IMPROVED AVIONICS AND CONTROLS	-	-	—	—
ELECTRICAL MACHINERY AND COMPONENTS	COMMUNICATION EQUIPMENT (SIC 366)	ELECTRONIC SWITCHING SYSTEMS (ESS)	-	•	AI	•
		TRANSMISSION INNOVATIONS	-	•	ADVANCED MATERIALS	•
		SATELLITE COMMUNICATIONS	-	•	LARGE GEO ANTENNA	•
		DIGITAL TRANSMISSION	-	-	—	—
		COMPUTER APPLICATION	-	•	AI	•
	ELECTRONIC COMPONENTS AND ACCESSORIES (SIC 367)	COMPUTER-DESIGNED SEMICONDUCTORS	-	•	AI	•
		AUTOMATED ASSEMBLY LINES	-	•	AI, PATTERN RECOGNITION	•
		NUMERICALLY CONTROLLED (NC) MACHINE TOOLS	-	-	—	—
		SUBMICROSTRUCTURAL SIZE OF SEMICONDUCTORS	-	•	ADVANCED MATERIALS	•
FOOD AND KINDRED PRODUCTS (SIC 20)	FOOD AND KINDRED PRODUCTS (SIC 20)	COMPUTER-CONTROLLED PROCESSING	-	•	AI	•
		REMOVAL OF CHOLESTEROL, SALT, FATS	-	-	—	—
		IONIZING RADIATION PRESERVATION	-	-	—	--
		SYNTHETIC SWEETNERS	-	-	—	--
		FLAVORED COLLAGENS	-	-	—	--
		ARTIFICIAL FOOD	-	•	BIOTECHNOLOGY	•

LEGEND
- \- NO
- • YES
- — NOT APPLICABLE

TABLE 2-17 (CONTINUED)
ASSESSMENT OF UNDERLYING CORE TECHNOLOGICAL ELEMENTS

SUBSECTOR	SUBDIVISION	INDUSTRY TECHNOLOGY PROGRAM	ASSESSMENT CRITERIA: HEMIBEL AS APPROACHED ?	ASSESSMENT CRITERIA: HEMIBEL FEASIBLE ?	KEY TECHNOLOGICAL ELEMENTS	FRUITION BY 2010
FABRICATED METALS (SIC 34)	FABRICATED STRUCTURAL METALS INDUSTRY (SIC 3441)	BEAMLINE TECHNOLOGY	-	-	—	—
		SEMI-AUTOMATED WELDING	-	-	—	—
		CNC PLATECUTTING	-	-	—	—
		OPTICAL TRACE CONTROL PLATECUTTING	-	-	—	—
		COLD CUTTING SAW	-	-	—	—
PRIMARY METALS (SIC 33)	STEEL INDUSTRY (SIC 331)	CONTINUOUS CASTING	-	-	—	—
		ELECTRIC-ARC FURNACE	-	-	—	—
		COMPUTER CONTROLS	-	•	AI	•
		VACUUM DEGASSING	-	-	—	—
		ADVANCED BASIC OXYGEN PROCESS (Q-BOP)	-	-	—	—
CHEMICALS AND ALLIED PRODUCTS (SIC 28)	PLASTIC MATERIALS AND SYNTHETICS (SIC 282)	L.P. CATALYTIC POLYMERIZATION	-	-	—	—
		INTERPENETRATING POLYMER NETWORKS	-	-	—	—
		LIQUID CRYSTAL POLYMERS	-	-	—	—
		INTRINSICALLY CONDUCTIVE POLYMERS	-	•	CUSTOM MULTIPROPERTY MATERIALS	•
	DRUGS (SIC 283)	DELIVERY SYSTEMS	-	•	MEDICAL TECHNOLOGY	—
		ENZYMATIC REACTORS	-	-	—	—
		IMMOBILIZED ENZYMES	-	-	—	—
		BIOPROCESS SEPARATION	-	•	BIOTECHNOLOGY	•
		BIOPROCESS SENSORS/CONTROLS	-	-	—	—
	INDUSTRIAL ORGANIC CHEMICALS (SIC 286)	C1 CHEMISTRY	-	-	—	—
		ZEOLYTE CATALYSTS	-	-	—	—
		ENZYMES	-	-	—	—
		SEPARATION	-	-	—	—
	AGRICULTURAL CHEMICALS (SIC 287)	HIGH EFFICIENCY AMMONIA PROCESS	-	-	—	—
		BIOPESTICIDES	-	•	BIOTECHNOLOGY	•
		BIOFERTILIZATION	-	•	BIOTECHNOLOGY	•
		ALLELOPATHY (BIOHERBICIDES)	-	•	BIOTECHNOLOGY	•
		COAL GASIFICATION	-	-	—	—
PETROLEUM REFINING AND RELATED INDUSTRIES (SIC 29)	PETROLEUM REFINING (SIC 291)	COMPUTER CONTROLLED REFINING	-	•	AI	•
		CATALYST DEVELOPMENT	-	-	—	—
		ENERGY CONSERVATION METHODS	-	-	—	—
		PREVENTIVE MAINTENANCE TECHNOLOGY	-	-	—	—
		MULTIFUEL CAPACITY PLANTS	-	-	—	—
PRINTING AND PUBLISHING (SIC 27)	NEWSPAPER PUBLISHING AND PRINTING (SIC 271)	ELECTRONIC COMPOSITION: TYPESETTING COMPUTERS, VDTs, PHOTO TYPESETTING,	-	•	AI, PATTERN RECOGNITION	•
		DATA TRANSMISSION	-	-	—	—
		SCANNERS-OPTICAL AND ELECTRONIC	-	•	AI, PATTERN RECOGNITION	•
		WEB-OFFSET PRINTING	-	-	—	—
		BINDING OPERATIONS	-	-	—	—
		NEWSPAPER MAILROOM	-	-	—	—
	COMMERCIAL PRINTING (SIC 275)	PREPRESS: WIDESPREAD USE OF COLOR PRINTING	-	-	—	—
		PRINTING: CLOSED LOOP PRINTING, MULTI-PLANT PRINTING VIA SATELLITE COMMUNICATION	-	•	AI, PATTERN RECOGNITION, LIVE PRESENCE COMMUNICATION	•
		ASSEMBLY: ELECTRONIC SENSING	-	•	AI, PATTERN RECOGNITION	•
PAPER AND ALLIED PRODUCTS (SIC 26)	CONVERTED PAPER AND PAPERBOARD PRODUCTS (SIC 264)	DEVELOPMENT OF REPULPABLE TAPE	-	-	—	—
		AUTOMATED TAPE AND LABEL APPLICATION	-	-	—	—
		COMPUTERIZED LABEL IMPRINTING EQUIPMENT	-	-	—	—

LEGEND - NO
• YES
— NOT APPLICABLE

TABLE 2-17 (CONTINUED)
ASSESSMENT OF UNDERLYING CORE TECHNOLOGICAL ELEMENTS

SUBSECTOR	SUBDIVISION	INDUSTRY TECHNOLOGY PROGRAM	ASSESSMENT CRITERIA HEMIBEL AS APPROACHED?	ASSESSMENT CRITERIA HEMIBEL FEASIBLE?	KEY TECHNOLOGICAL ELEMENTS	FRUITION BY 2010
	PAPERBOARD CONTAINERS AND BOXES (SIC 265)	IMPROVED PRINTING PROCESSES	-	-	—	—
		RADIATION INK CURING	-	-	—	—
		IMPROVED EQUIPMENT FOR CUTTING AND CREASING	-	-	—	—
		COMPUTER & LASER METHODS TO PREPARE DIES	-	•	AI	•
		AUTOMATIC STRIPPING OF WASTE	-	-	—	—
		NEW TECHNOLOGY TO GLUE CARTONS	-	-	—	—
		IMPROVED PACKING METHODS	-	-	—	—
	PULP, PAPER, AND BOARD MILLS (SICS 261,262,263,266)	MECHANIZATION OF MATERIALS HANDLING	-	-	—	—
		IMPROVED PULPING TECHNOLOGY	-	-	—	—
		IMPROVED PAPERMAKING MACHINES	-	-	—	—
		COMPUTER CONTROL AND INSTRUMENTATION	-	•	AI, PATTERN RECOGNITION	•
		POLLUTION CONTROL TECHNOLOGY	-	-	—	—
INSTRUMENTS AND RELATED PRODUCTS (SIC 38)	PHOTOGRAPHIC EQUIPMENT AND SUPPLIES (SIC 386)	ELECTRONIC STILL CAMERA	-	-	—	—
		ELECTRONIC IMAGING	-	-	—	—
		COLOR FILM PRINTERS	-	-	—	—
		INK JET PRINTERS	-	-	—	—
	SURGICAL, MEDICAL, AND DENTAL INSTRUMENTS (SIC 384)	CURATIVE TECHNOLOGY	-	•	MEDICAL TECHNOLOGY	•
		NEW MATERIALS PROSTHESIS	-	•	ADVANCED MATERIALS, AI	•
	OPTICAL INSTRUMENTS AND LENSES (SIC 383)	LASERS AND OPTIC FIBERS	-	•	PATTERN RECOGNITION, AI	•
		NONINVASIVE DIAGNOSTICS	-	•	MEDICAL TECHNOLOGY	•
STONE, GLASS, AND CLAY (SIC 32)	CONCRETE BLOCK, CONCRETE PRODUCTS, AND READY MIX CONCRETE (SICS 3271, 3272, 3273)	IMPROVED MATERIAL HANDLING EQUIPMENT	-	-	—	—
		IMPROVED CASTING METHODS	-	-	—	—
		AUTOMATIC BATCHERS	-	-	—	—
	ADVANCED CERAMICS	ELECTRONIC APPLICATIONS	-	•	ADVANCED MATERIALS	•
		HEAT ENGINE APPLICATIONS	-	•	ADVANCED MATERIALS	•
		CUTTING TOOL APPLICATIONS	-	•	ADVANCED MATERIALS	•
		WEAR PARTS APPLICATIONS	-	•	ADVANCED MATERIALS	•
RUBBER AND MISCELLANEOUS PRODUCTS (SIC 30)	MISCELLANEOUS PLASTICS PRODUCTS (SIC 307)	RESIN TRANSFER MOLDING	-	•	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	•
		TWIN SCREW EXTRUSION AND COMPOUNDING	-	•	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	•
		REACTION INJECTION MOLDING (RIM)	-	•	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	•
		SHEET MOLDING COMPOUND (SMC)	-	•	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	•
		PULTRUSION	-	•	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	•
		THERMOFORMING	-	•	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	•

LEGEND - NO
• YES
— NOT APPLICABLE

TABLE 2-17 (CONTINUED)
ASSESSMENT OF UNDERLYING CORE TECHNOLOGICAL ELEMENTS

SUBSECTOR	SUBDIVISION	INDUSTRY TECHNOLOGY PROGRAM	ASSESSMENT CRITERIA: HEMIBEL AS APPROACHED?	ASSESSMENT CRITERIA: HEMIBEL FEASIBLE?	KEY TECHNOLOGICAL ELEMENTS	FRUITION BY 2010
		SHEET AND FILM COEXTRUSION AND LAMINATION	-	●	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	●
		INJECTION BLOW-MOLDING AND COEXTRUSION BLOW MOLDING	-	●	ADVANCED MATERIALS, BIOTECHNOLOGY, CUSTOM MULTI-PROPERTY MATERIALS	●
WHOLESALE AND RETAIL TRADE (SICS 50-59)	GROCERIES AND RELATED PRODUCTS (SIC 514)	CODING OF INVENTORY	-	-	—	—
		COMPUTERIZATION	-	●	AI	●
		AUTOMATED WAREHOUSING	-	●	AI, PATTERN RECOGNITION	●
	FOOD STORES (SIC 54)	COMPUTERIZED CASH REGISTERS	-	-	—	—
		MICROFILMING	-	-	—	—
		ATMs AND EFTs	-	-	—	—
		VIDEODISCS AND CATV	-	●	LIVE PRESENCE COMMUNICATION, AI, PATTERN RECOGNITION	●
GOVERNMENT AND GOVERNMENT ENTERPRISES (SICS 90-97)	EDUCATION	ARTIFICIAL INTELLIGENCE	-	●	AI	●
		EDUCATION STATIONS, DISPLAYS	-	●	AI	●
		COMMUNICATIONS	-	●	LIVE PRESENCE COMMUNICATION	●
		BEHAVIOR MODIFICATION	-	●	MEDICAL TECHNOLOGY	●
		NEUROPHYSIOLOGY	-	●	MEDICAL TECHNOLOGY	●
FINANCE, INSURANCE AND REAL ESTATE	COMMERCIAL AND STOCK SAVINGS BANKS	IN-HOME INFORMATION	-	●	LIVE PRESENCE COMMUNICATION, AI	●
		ELECTRONIC FUNDS TRANSFER	-	-	—	—
TRANSPORTATION SERVICES (SICS 41, 42,44,45,46,47)	LINE HAUL OPERATING RAILROADS (SIC 401)	MOTIVE POWER DEVELOPMENTS	-	-	—	—
		FREIGHT CAR IMPROVEMENTS	-	-	—	—
		PIGGYBACK/UNIT TRAINS	-	-	—	—
		AUTOMATIC CLASSIFICATION YARDS	-	-	—	—
		CENTRALIZED TRAFFIC CONTROL	-	-	—	—
		SIGNALING AND COMMUNICATIONS	-	-	—	—
		MAINTENANCE OF WAY INNOVATIONS	-	-	—	—
	INTERCITY TRUCKING (SIC 42)	GREATER TRAILER CAPACITY	-	-	—	—
		DIESEL POWERED ENGINES	-	-	—	—
		LIGHTER TRICK BODY AND TIRES	-	-	—	—
		COMPUTER APPLICATIONS	-	-	—	—
	AIR TRANSPORTATION (SIC 45)	MORE EFFICIENT AIRFRAMES AND ENGINES	-	-	—	—
		NAVIGATIONAL ADVANCES	-	●	AI, PATTERN RECOGNITION	●
		SURVEILLANCE AND COLLISION CONTROL DEVELOPMENTS	-	●	AI, PATTERN RECOGNITION	●
		DEVELOPMENTS IN TRAFFIC FLOW	-	●	AI	●
		AUTOMATED AIRPORT TERMINALS	-	●	AI, PATTERN RECOGNITION	●
	WATER TRANSPORTATION	CARGO CONTAINERIZATION	-	-	—	—
		INCREASED CARGO CAPACITY	-	-	—	—
		CENTRALIZED ENGINE CONTROLS	-	-	—	—
		BOW THRUSTS	-	-	—	—
		IMPROVED MARINE COATINGS	-	-	—	—
		VESSEL TRAFFIC MANAGEMENT SYSTEMS	-	-	—	—
		PERFORMANCE MONITORING SYSTEMS	-	-	—	—
		GLOBAL POSITIONING SYSTEM	-	-	—	—

LEGEND - NO
● YES
— NOT APPLICABLE

TABLE 2-17 (CONTINUED)
ASSESSMENT OF UNDERLYING CORE TECHNOLOGICAL ELEMENTS

SUBSECTOR	SUBDIVISION	INDUSTRY TECHNOLOGY PROGRAM	ASSESSMENT CRITERIA: HEMIBEL AS APPROACHED?	ASSESSMENT CRITERIA: HEMIBEL FEASIBLE?	KEY TECHNOLOGICAL ELEMENTS	FRUITION BY 2010
COMMUNICATION	TELEPHONE COMMUNICATION (SIC 481)	SATELLITE COMMUNICATIONS	-	●	LARGE GEO ANTENNA	●
		FIBER OPTICS	-	●	LIVE PRESENCE COMMUNICATIONS	●
		CELLULAR MOBILE TELEPHONE	-	●	LARGE GEO ANTENNA	●
		ELECTRONIC SWITCHING SYSTEM	-	●	AI	●
CONSTRUCTION (SIC 15,16,17)	RESIDENTIAL CONSTRUCTION	COMPUTER-AIDED DESIGN (CAD)	-	●	AI	●
		COMPUTER-AIDED MANUFACTURE (CAM)	-	●	AI, PATTERN RECOGNITION	●
		NEW MATERIALS	-	●	ADVANCED MATERIALS	●
	NONRESIDENTIAL CONSTRUCTION	COMPUTER-AIDED DESIGN (CAD)	-	●	AI	●
		COMPUTER-AIDED MANUFACTURE (CAM)	-	●	AI, PATTERN RECOGNITION	●
		NEW MATERIALS	-	●	ADVANCED MATERIALS	●
MINING (SICS 10, 11,12,13,14)	PETROLEUM EXTRACTION (SIC 13)	TERTIARY METHODS OF OIL EXTRACTION	-	-	—	—
		OIL PRODUCTION FROM ALTERNATIVE SOURCES	-	-	—	—
		ALTERNATIVE METHODS OF NATURAL GAS EXTRACTION	-	-		
	COAL MINING (SIC 11, 12)	IMPROVEMENTS IN SURFACE MINING	-	-	—	—
		LONGWALL MINING SYSTEMS	-	-	—	—
		CONTINUOUS MINERS & SUPPLY PIPELINES	-	-	—	—
		USE OF COMPUTERS	-	●	AI	●
		TELEOPERATORS	-	●	LIVE PRESENCE COMMUNICATION, PATTERN RECOGNITION, AI	●

LEGEND - NO
● YES
— NOT APPLICABLE

underlie many of the 180 technology programs underway in the 20 subsectors we reviewed. A "pervasive" technology is one that benefits a broad class of industry applications. R&D in these technologies would have particularly high payoff and represent the thrusts NASA should consider as candidates for an innovative industrial-oriented technology program.

These are, however, not the only technologies which the economy requires. A broader set of needs, not apparent from review of the technology programs being pursued by industry, derives from consideration of the constraints which affect industry and the entire economy. As indicated in Table 2-18, we assessed the major constraints which are potentially addressable by technology as:

- The long times needed for training and retraining elements of the U.S. workforce to provide adequate levels of skill.

- The dearth of professional technical personnel, due in part to the long and expensive educational requirements.

- The consumption of time and resources to physically move people, to and from work, school, business meetings, stores.

These constraints are currently taken for granted, thus techniques and technologies for their alleviation are not directly addressed in the roster of technology programs. Their correction, even though only partial, would nevertheless induce a major enhancement of U.S. productivity. For example, the Bureau of Labor Statistics forecasts that by the turn of this century, 3% of the U.S. workforce will appear to be unemployed, not from lack of occupation, but rather because the accelerating pace of technology will require extensive and continuing retraining.

TABLE 2-18

TECHNOLOGIES ADDRESSING DOMINANT INDUSTRY CONSTRAINTS

SUBSECTOR	SUBDIVISION	DOMINANT CONSTRAINTS	CAN TECHNOLOGY SOLVE?	UNDERLYING CORE TECHNOLOGY
MACHINERY EXCEPT ELECTRICAL (SIC 35)	ENGINES AND TURBINES (SIC 351)	FISCAL/MONETARY POLICY	-	—
		LIMITED MARKET/CUSTOMERS	-	—
		REGULATORY ENVIRONMENT	-	—
		LIMITED CAPITAL FOR UTILITIES	-	—
	METALWORKING MACHINERY AND EQUIPMENT (SIC 354)	GOVERNMENT INTERACTION	-	—
		GOVERNMENT REGULATION	-	—
		OWNERSHIP STRUCTURE	-	—
		WORKER AGE	-	—
		AVAILABILITY OF YOUNGER WORKERS	-	—
		TRAINING PERIOD FOR SKILLED OPERATORS	•	ACCELERATED LEARNING
		AVERAGE QUALITY OF MANAGEMENT	-	—
		QUALITY OF ENGINEERING	•	ACCELERATED LEARNING
		AVAILABILITY OF ENGINEERING TALENT	•	ACCELERATED LEARNING
		FISCAL/MONETARY POLICY	-	—
		AVAILABILITY OF INVESTMENT CAPITAL	-	—
		MARKET DEMAND PATTERNS	-	—
	OFFICE, COMPUTING AND ACCOUNTING EQUIPMENT (SIC 357)	FEDERAL CLEAN AIR AND WATER ACT	-	—
		U.S. ECONOMIC STRENGTH	-	—
		CONTINUED TELECOMMUNICATIONS DEREGULATION	-	—
		CHEAP FOREIGN LABOR	•	ROBOTICS, AI, PATTERN RECOGNITION
		HORIZONTAL CORPORATE STRUCTURE	-	—
TRANSPORTATION EQUIPMENT (SIC 37)	MOTOR VEHICLES (SIC 371)	GOVERNMENT REGULATIONS	-	—
		FUEL PRICES	•	MOBILE ENERGY STORAGE
		LABOR RELATIONS	-	—
		FISCAL/MONETARY POLICY	-	—
	AIRCRAFT AND PARTS (SIC 372)	GOVERNMENT INTERACTION	-	—
		GOVERNMENT REGULATION	-	—
		OWNERSHIP STRUCTURE	-	—
		QUALITY OF MANAGEMENT	-	—
		QUALITY OF ENGINEERING	•	ACCELERATED LEARNING
		AVAILABILITY OF ENGINEERING	•	ACCELERATED LEARNING
		AVAILABILITY OF INVESTMENT CAPITAL	-	—
		MARKET DEMAND PATTERN	-	—
ELECTRICAL AND ELECTRONIC MACHINERY (SIC 36)	COMMUNICATION EQUIPMENT (SIC 366) (SIC 366)	GOVERNMENT INTERACTION	-	—
		GOVERNMENT REGULATION	-	—
		OWNERSHIP STRUCTURE	-	—
		FISCAL/MONETARY POLICY	-	—
	ELECTRONIC COMPONENTS INDUSTRY (SIC 367)	RESEARCH AND DEVELOPMENT	-	—
		AVAILABILITY OF INVESTMENT CAPITAL	-	—
		AVAILABILITY OF ENGINEERS	•	ACCELERATED LEARNING
		AVAILABILITY OF SKILLED WORKERS	•	ACCELERATED LEARNING
		FISCAL/MONETARY POLICY	-	—
		MARKET DEMAND PATTERN	-	—
FOOD AND KINDRED PRODUCTS (SIC 20)	FOOD AND KINDRED PRODUCTS (SIC 20)	AGRICULTURE	•	BIOTECHNOLOGY
		GOVERNMENT REGULATION	-	—
		TRANSPORTATION COSTS	•	MOBILE ENERGY STORAGE, BIOTECHNOLOGY
		FISCAL/MONETARY POLICY	-	—

LEGEND
- \- NO
- • YES
- — NOT APPLICABLE

TABLE 2-18 (CONTINUED)

TECHNOLOGIES ADDRESSING DOMINANT INDUSTRY CONSTRAINTS

SUBSECTOR	SUBDIVISION	DOMINANT CONSTRAINTS	CAN TECHNOLOGY SOLVE?	UNDERLYING CORE TECHNOLOGY
FABRICATED METAL PRODUCTS (SIC 34)	FABRICATED STRUCTURAL METAL (SIC 3441)	GOVERNMENT REGULATION	-	—
		LACK OF INNOVATION	-	—
		LABOR RELATIONS	-	—
		TRAINING PERIOD FOR SEMI-SKILLED OPERATORS	●	ACCELERATED LEARNING
		CUSTOMIZED (BATCH) PRODUCTS	●	AI, PATTERN RECOGNITION
		FISCAL/MONETARY POLICY	-	—
		AVAILABILITY OF INVESTMENT CAPITAL	-	—
		MARKET DEMAND PATTERN	-	—
PRIMARY METALS (SIC 33)	STEEL INDUSTRY (SIC 331)	GOVERNMENT REGULATIONS	-	—
		LABOR RELATIONS	-	—
		FISCAL/MONETARY POLICY	-	—
		UTILITY (WATER) COST	-	—
CHEMICALS AND ALLIED PRODUCTS (SIC 28)	PLASTIC MATERIALS AND SYNTHETICS	RAW MATERIALS COSTS	●	ADVANCED MATERIALS
		EFFICIENCY OF PROCESS INNOVATIONS	●	ROBOTICS, AI, PATTERN RECOGNITION
		NEW MATERIALS DEVELOPMENT COSTS	●	ADVANCED MATERIALS
	DRUGS (SIC 283)	GOVERNMENT REGULATIONS	-	—
		FUEL AND MATERIAL COSTS	●	ADVANCED MATERIALS
		PRODUCTION ESTABLISHMENT REQUIRES HIGHLY SKILLED EMPLOYEES	●	ACCELERATED LEARNING
		FISCAL/MONETARY POLICY	-	—
		CAPITAL INTENSIVE	-	—
	INDUSTRIAL ORGANIC CHEMICALS (SIC 286)	GOVERNMENT REGULATIONS	-	—
		FUEL AND FEEDSTOCK COSTS	●	ADVANCED MATERIALS
		LABOR STRUCTURE (EMPLOYMENT DECLINING)	-	—
		FISCAL/MONETARY POLICY	-	—
		CAPITAL INTENSIVE	-	—
	AGRICULTURAL CHEMICALS (SIC 287)	GOVERNMENT REGULATIONS	-	—
		FUEL AND FEEDSTOCK COSTS	●	ADVANCED MATERIALS
		LABOR STRUCTURE (EMPLOYMENT DECLINING)	-	—
		AGED PLANTS AND EQUIPMENT	-	—
		FISCAL/MONETARY POLICY	-	—
		CAPITAL INTENSIVE	-	—
PETROLEUM REFINING AND RELATED INDUSTRIES (SIC 29)	PETROLEUM REFINING (SIC 291)	GOVERNMENT REGULATIONS	-	—
		LABOR RELATIONS	-	—
		FISCAL/MONETARY POLICY	-	—
PRINTING AND PUBLISHING (SIC 27)	NEWSPAPER PUBLISHING AND PRINTING (SIC 271)	DISTRIBUTION FUNCTIONS	-	—
		LABOR RELATIONS	-	—
		MATERIAL LIMITATIONS	●	ADVANCED MATERIALS
	COMMERCIAL PRINTING (SIC 275)	MATERIAL SHORTAGES	●	ADVANCED MATERIALS
		LACK OF SKILLED WORKERS	●	ADVANCED MATERIALS
		INDUSTRY FRAGMENTATION	-	—
PAPER AND ALLIED PRODUCTS (SIC 26)	MISCELLANEOUS CONVERTED PAPER PRODUCTS (SIC 264)	GOVERNMENT REGULATIONS	-	—
		FUEL COSTS	●	ADVANCED MATERIALS
		CAPITAL INVESTMENT (HIGH)	-	—
	PAPERMILLS, EXCEPT BUILDING PAPER (SIC 262)	GOVERNMENT REGULATIONS	-	—
		FUEL COSTS	●	ADVANCED MATERIALS
		CAPITAL INVESTMENT (HIGH)	-	—
	PAPERBOARD CONTAINERS AND BOXES (SIC 265)	GOVERNMENT REGULATIONS	-	—
		FUEL COSTS	●	ADVANCED MATERIALS
		CAPITAL INVESTMENT (HIGH)	-	—

LEGEND
- \- NO
- ● YES
- — NOT APPLICABLE

TABLE 2-18 (CONTINUED)

TECHNOLOGIES ADDRESSING DOMINANT INDUSTRY CONSTRAINTS

SUBSECTOR	SUBDIVISION	DOMINANT CONSTRAINTS	CAN TECHNOLOGY SOLVE?	UNDERLYING CORE TECHNOLOGY
INSTRUMENTS AND RELATED PRODUCTS (SIC 38)	OPITCAL INSTRUMENTS AND LENSES (SIC 383)	MONETARY POLICY	-	—
		SHORTAGES OF SCIENTISTS/ENGINEERS	●	ACCELERATED LEARNING
		PATENT FEES	-	—
		LACK OF INDUSTRY STANDARD	-	—
	SURGICAL, MEDICAL, AND DENTAL INSTRUMENTS (SIC 384)	GOVERNMENT REGULATIONS	-	—
		MONETARY POLICY	-	—
		PRICE STABILIZATION PRESSURES	-	—
	PHOTOGRAPHIC EQUIPMENT AND SUPPLIES (SIC 386)	FISCAL/MONETARY POLICY	-	—
		CYCLICAL MARKET DEMAND	-	—
		INVESTMENT RISK	-	—
		LACK OF VERTICAL INTEGRATION IN CORPORATE STRUCTURE	-	—
STONE, GLASS, AND CLAY (SIC 32)	CONCRETE AND CONCRETE PRODUCTS INDUSTRIES (SICS 3271, 3272, 3273)	HIGHLY FRAGMENTED OWNERSHIP	-	—
		LACK OF INNOVATION	-	—
		FISCAL/MONETARY POLICY	-	—
		LOW AVAILABILITY OF INVESTMENT CAPITAL	-	—
		CYCLICAL MARKET DEMAND	-	—
	ADVANCED CERAMICS	LACK OF ENGINEERS	●	ACCELERATED LEARNING
		INSUFFICIENT R&D	-	—
		LACK OF INDUSTRY STANDARDS	-	—
		CATASTROPHIC FAILURE PROBLEM	●	ADVANCED MATERIALS
RUBBER AND MISCELLANEOUS PRODUCTS (SIC 30)	MISCELLANEOUS PLASTICS PRODUCTS (SIC 307)	COST OF MATERIALS	●	ADVANCED MATERIALS
WHOLESALE AND RETAIL TRADE (SICS 50-59)	GROCERIES AND RELATED PRODUCTS (SIC 514)	PRODUCT LIABILITY	-	—
		BANKRUPTCY REFORM	-	—
		MULTIEMPLOYER PENSION ACT	-	—
	FOOD STORES (SIC 54)	SLOW POPULATION GROWTH	-	—
		FOOD PRICES	●	BIOTECHNOLOGY
		CASH LOSSES DUE TO "CHECK-FLOAT"	-	—
GOVERNMENT AND GOVERNMENT ENTERPRISES (SICS 90-97)	EDUCATION	NEED FOR WORKFORCE TO RETRAIN MORE OFTEN DUE TO TECHNOLOGICAL DEVELOPMENTS	●	ACCELERATED LEARNING
		SCHOOL CLOSINGS DUE TO DROP IN BIRTH RATES	-	—
		LOW QUALITY INCOMING TEACHERS DUE TO LOW SALARIES AND A LACK OF PRESTIGE	-	—
		AGING OF TEACHING POPULATION	-	—
FINANCE, INSURANCE, AND REAL ESTATE (SICS 60-67)	COMMERCIAL AND STOCK SAVINGS BANKS	GOVERNMENT REGULATIONS	-	—
		INCREASED COMPETITION FROM OTHER INDUSTRIES	-	—
		FISCAL/MONETARY POLICY	-	—
	SAVINGS AND LOAN ASSOCIATIONS	GOVERNMENT REGULATIONS	-	—
		INCREASED COMPETITION FROM OTHER INDUSTRIES	-	—
		FISCAL/ MONETARY POLICY	-	—

LEGEND
- \- NO
- ● YES
- — NOT APPLICABLE

TABLE 2-18 (CONTINUED)

TECHNOLOGIES ADDRESSING DOMINANT INDUSTRY CONSTRAINTS

SUBSECTOR	SUBDIVISION	DOMINANT CONSTRAINTS	CAN TECHNOLOGY SOLVE?	UNDERLYING CORE TECHNOLOGY
TRANSPORATION SERVICES (SICS 41,42,44,45,46,47)	RAILROAD TRANSPORTATION (SIC 4011)	LABOR INTENSIVE INDUSTRY	-	—
		CAPITAL INTENSIVE INDUSTRY	-	—
		GOVERNMENT REGULATION	-	—
	TRUCKING (SIC 421)	FUEL COSTS	●	MOBILE ENERGY STORAGE
		LABOR INTENSIVE INDUSTRY	-	—
		GOVERNMENT REGULATION	-	—
	AIR TRANSPORTATION (SIC 451)	GOVERNMENT REGULATION	-	—
		FUEL COSTS	●	MOBILE ENERGY STORAGE
		CAPITAL INTENSIVE INDUSTRY	-	—
	WATER TRANSPORTATION (SIC 44)	CAPITAL INTENSIVE INDUSTRY	-	—
		SLOW MARKET GROWTH	-	—
COMMUNICATION SERVICES (SIC 48)	TELEPHONE COMMUNICATIONS (SIC 481)	GOVERNMENT REGULATION	-	—
		AVAILABILITY OF SKILLED WORKERS	●	ACCELERATED LEARNING
CONSTRUCTION (SICS 15,16,17)	RESIDENTIAL BUILDING CONSTRUCTION	HIGH INTEREST RATES	-	—
		HIGH UNEMPLOYMENT	-	—
		SLOW GROWTH IN DISPOSABLE PERSONAL INCOME	-	—
	NONRESIDENTIAL BUILDING CONSTRUCTION	HIGH INTEREST RATES	-	—
		HIGH UNEMPLOYMENT	-	—
		SLOW MARKET GROWTH	-	—
MINING (SICS 10-14)	CRUDE OIL AND NATURAL GAS INDUSTRY (SIC 131)	COST OF EXPLORATION	●	LIVE PRESENCE COMMUNICATION, PATTERN RECOGNITION, AI
			-	
		DWINDLING RESERVES	-	—
	COAL MINING (SICS 11,12)	SAFETY FACTORS	●	LIVE PRESENCE COMMUNICATION, PATTERN RECOGNITION, AI
		GOVERNMENT REGULATION	-	—
		TRANSPORTATION COSTS	●	MOBILE ENERGY STORAGE

LEGEND
- \- NO
- ● YES
- — NOT APPLICABLE

Technologies to alleviate those constraints which are technologically addressable are "pervasive" by their very nature. We assessed their probable time span of future fruition, and included in our technology thrusts those which appeared capable of being achieved by 2005-2010.

Consolidating these with the long-term requirements of the 20 industrial subsectors that we examined, we identified nine pervasive technologies. Described in detail in Volume V, Sections E.1 through E.10, these are synopsized below.

1. **Hyperstrength Materials**--with strength-to-weight ratios not heretofore available, or that provide economical substitutes for available materials. Example are high-strength plastics such as Kevlar, replacing metals.

2. **Custom Multi-Property Materials**--having characteristics tailored to fit specific applications. Example are engine blocks requiring no machining and exhibiting hardness and heat resistance in the cylinder zone and resilience in the mounting area.

3. **Mobile Energy Storage Devices**--such as high energy density batteries for transportation. Such devices would allow stationary energy sources, plentiful in the U.S., to be exploited in mobile applications such as electric cars. These devices would also support important needs of Electrical Machinery and Components (SIC 36), and Instruments and Related Products (SIC 38).

4. **Live Presence Communications**--the ability to intercommunicate in such a way as to obviate the need for physical presence, thereby reducing the need for personal travel. Current teleconferencing technology is a primitive example. Communications technology does not appear to be a limitation in achieving more realistic

interfacing; what requires research is the deeper understanding of the mechanism of interpersonal information transfer.

5. **Information Rationalization**--vastly improved techniques for extracting cogent information from the growing number of databases. The value of current databases is limited by the mismatch between what they contain and what the user actually needs. As an example, consider the question: "Which machine tool represents the best solution to a new milling requirement?" Advances in computer storage technology make it practical to store on-line all relevant data on milling equipment and processes found in brochures, catalogs, books, and reports. Memory alone, however, will not provide the "answer" the user seeks. What are needed are interactive techniques that will "rationalize" the available information, i.e., "prompt" the user to refine the question to the point where the information handling system can exploit, sift, integrate all the information on milling at its disposal and provide a specific solution with supporting rationale. Currently, such inquiries are handled heuristically, and require extensive human interaction and time. The object of improved "information rationalization" techniques is to provide optimized answers rapidly. This capability will enhance industrial productivity across the board.

6. **Accelerated Learning**--advanced techniques for acquiring new skills and enhancing basic education processes. Training is becoming increasingly important throughout our economy. The slow pace of human learning retards productivity. Typically, a skilled metalworking machinist requires 8,000 hours of training; a photointerpreter, 9000; a computer programmer, from 1,000 to 4,000 hours--during which time full productivity is not

achieved. By 2000, the Bureau of Labor Statistics estimates that as much as 3% of the U.S. workforce will be continuously engaged in new learning or retraining. Experimental work in teaching foreign languages and specialized skills points to the potential for significant acceleration of the skill training process, with consequent improvement of productivity. Accelerated learning technology may also be applicable to basic learning processes, with attendant long-term impact on the country's basic educational system.

7. **Artificial Reasoning**--technologies for achieving electronic and/or biotechnical systems capable of performing many of the higher-level functions of the human brain, commonly referred to as the reasoning processes. Achievement of these technologies would represent the culmination of that body of ongoing research known as "artificial intelligence." They go far beyond the technologies of robotics as we now know them, by embodying elements of adaptiveness and machine learning which as yet we do not know how to incorporate into our computing hardware and software.

   The impact of these technologies upon industrial productivity would be highly significant: Their achievement, even to a relatively limited extent, would essentially recreate the ancient "slave" economy, without any of its negative implications.

8. **Biotechnology**--advanced techniques for the "customized" generation of biological systems. Economic applications, currently being researched for the near and medium-terms, include the breeding of special traits in plants and animals, of singular strains of microorganisms and organic drugs for medicinal purposes, and in general the spectrum of research known as genetic engi-

neering. Advanced industrial applications would range from microorganisms capable of concentrating diluted materials, e.g. metals from ores, to systems capable of "growing" industrial materials with multiple properties, to organic "controller" and perhaps even reasoning system. The end purpose of biotechnical research is the development of engineering rules and methods for creating structures of organic matter, tailored to achieve pre-assigned specifications. Its significance to industry is that living organisms possess mechanisms, e.g., enzymes, which make them far more versatile, adaptive and multiform than ordinary materials. In theory, the properties which can be engineered into products of living matter appear to be almost unlimited in scope.

9. **Pattern Recognition**--technologies which can endow inanimate--e.g., electronic--systems with discrimination and synthesis capabilities akin to those of the human sensory-brain system. The human visual system and the auric and/or tactile systems, which include sensors, brain and efferent communications systems, are unmatched in discerning complex relationships. Development of automated systems approaching human capabilities would impact industrial productivity by enhancing processes or replacing operations currently requiring man's intervention. Further, these systems can be coupled to the capabilities of advanced electromechanical sensors, greater than, albeit not as flexible as, those of human sensors, to achieve major quantitative and qualitative enhancement of industrial automation.

CHAPTER 3

TECHNOLOGY REQUIREMENTS FOR SUPPORT OF NONECONOMIC NATIONAL NEEDS

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3.0 TECHNOLOGY REQUIREMENTS FOR SUPPORT OF OTHER THAN ECONOMIC NEEDS

3.1 OVERVIEW

U.S. technology requirements do not stem solely from economic needs. They derive as well from other national aspirations, including the aim of improving health care and security and satisfying less tangible goals such as the general state of well-being symbolized by Jefferson as the "pursuit of happiness."

This chapter describes the findings of the Step 1 process, Figure 1-1, applied to these noneconomic aspirations. We adopted the following terminology to characterize them:

- **Health**--maintenance of physical and psychological well-being

- **Security**--protection from man-made and/or natural violence

- **Pursuit of Happiness**--the capacity to reach high levels of self-fulfillment and societal development

Figure 3-1 compares the allocation of U.S. resources (percentage of GNP) to the three categories of aspirations with the resources devoted to the nation's economic pursuits--"wealth." It indicates that, over the period 1950-1980, commitments to "Health," "Security" and "Pursuit of Happiness" have increased their proportion of GNP by more than 50%. Trends indicate that these needs will continue to command increasing proportions of the nation's resources.

The sections that follow compare the degree of achievement of these aspirations in the U.S. and other principal developed nations. They assess techniques and technologies that address

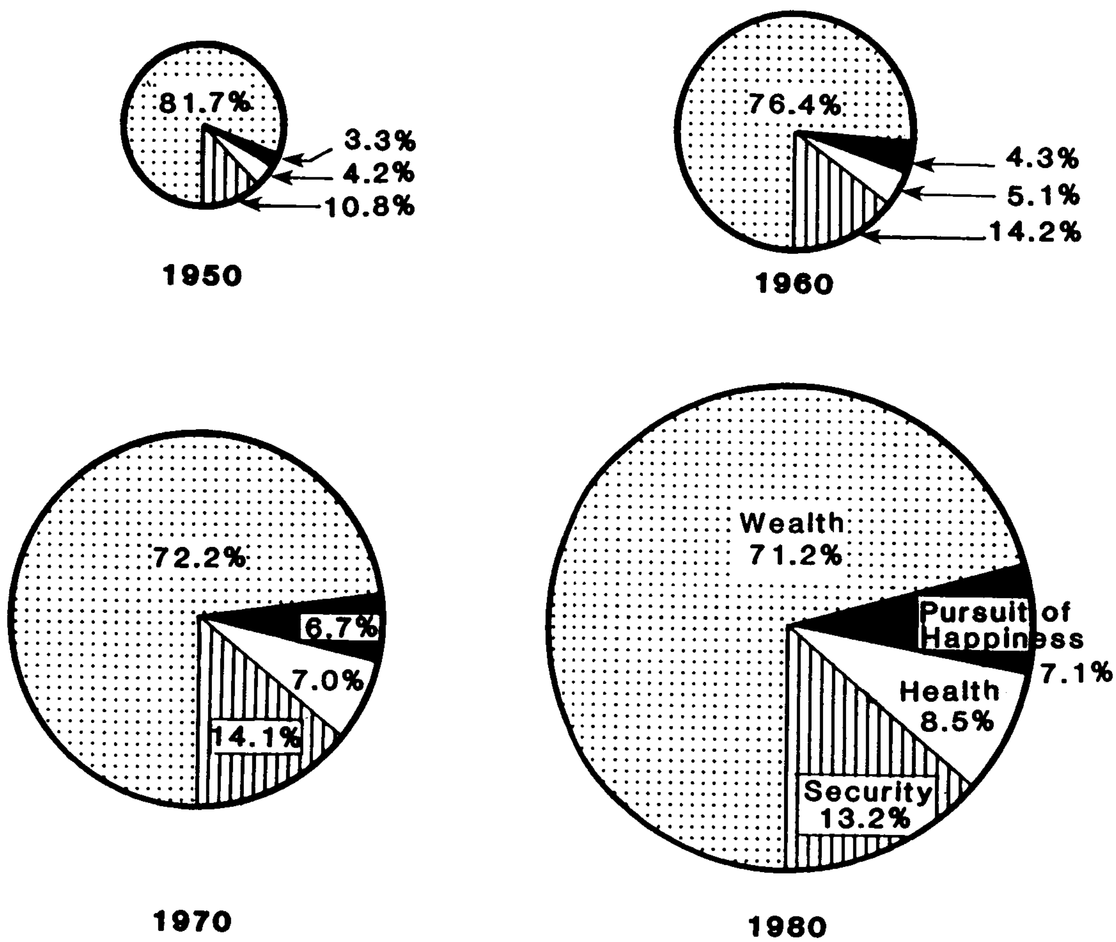


Figure 3-1. Relative Allocation of U.S. Resources Among Economic and Non-Economic Aspirations (In Percent of GNP at Constant Dollars -- Includes Public and Private Expenditures)

these aspirations and "leapfrog" measures which could produce major advances by 2005-2010. Volume III, Sections C.1 through C.3, details our findings.

3.2 HEALTH

The desire for physical and mental well-being implies freedom from disease and organic handicaps, and correction of conditions caused by untoward situations and accidents. It also implies a desire to extend life expectancy under healthful conditions.

To identify long-term technologies that support health aspirations, we categorized their components and compiled indicators of posture and trends. In order to uncover "weak" areas potentially addressable by technology, we compared the current U.S. posture with respect to its historical progress and to the state-of-the-art in other developed nations.

Figure 3-2 is a categorization of health aspirations that we adopted from standard classifications in use by the World Health Organization and the National Institutes of Health.

Review of the literature and discussions with U.S. health experts suggested four indicators of health posture:

- **Quality measures**--such as: incidence of pathogenic and organic diseases; percentage of corrected physical handicaps; level of education of medical care personnel.

- **Quantity measures**--such as volume of medical facilities per 100,000 population, e.g., medical care personnel, hospitals and hospital beds, diagnostic and therapeutic equipment.

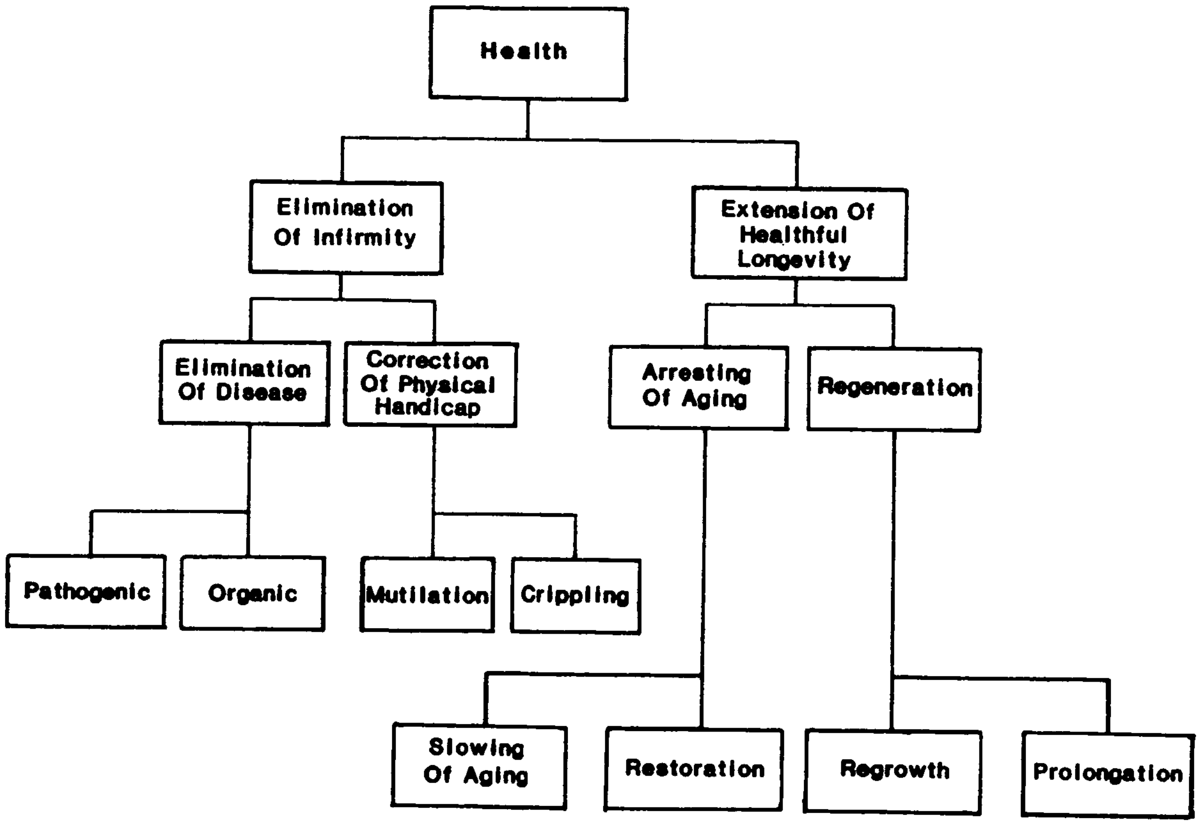


Figure 3-2. Categorization of Health Aspirations

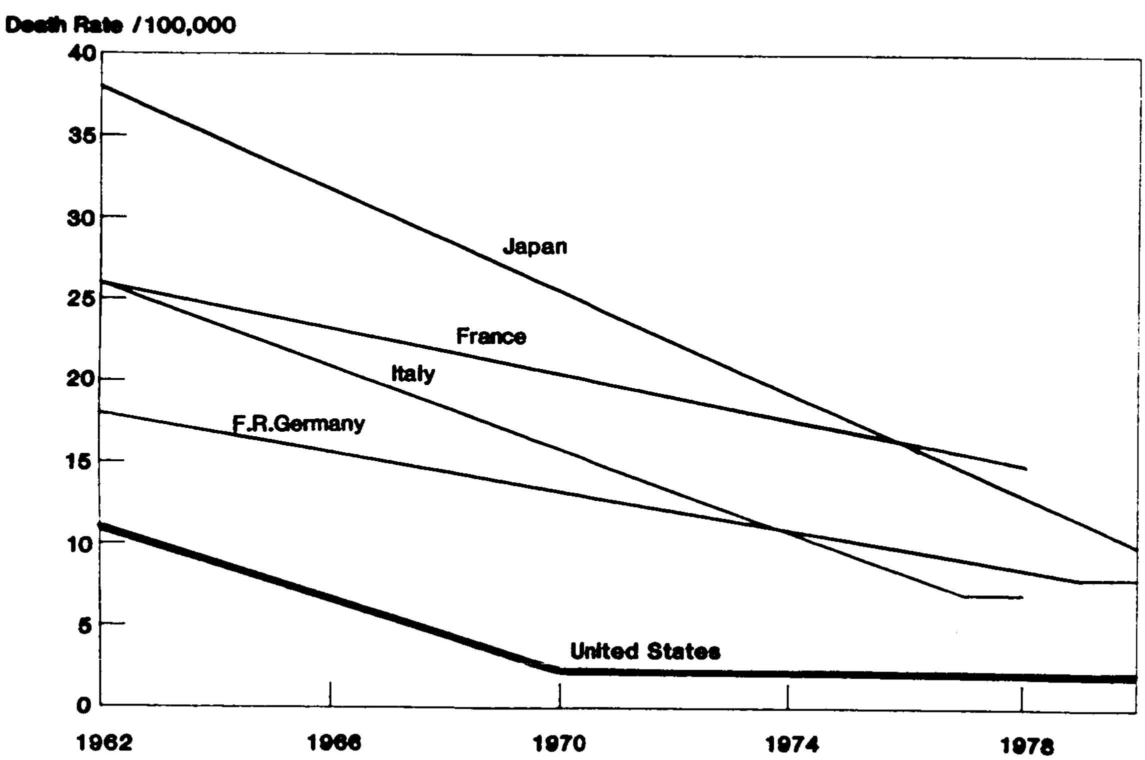


Figure 3-3. Infectious and Parasitic Diseases

- **Productivity measures**--such as degree of utilization of available health facilities, e.g., the occupancy rate of hospitals and hospital beds.

- **Equity indicators**--such as fairness of access to, and affordability of medical care by diverse socioeconomic strata.

3.2.1 PROGRESS AND COMPARATIVE POSTURE OF THE U.S. AND PRINCIPAL DEVELOPED NATIONS

Quality of Health Care

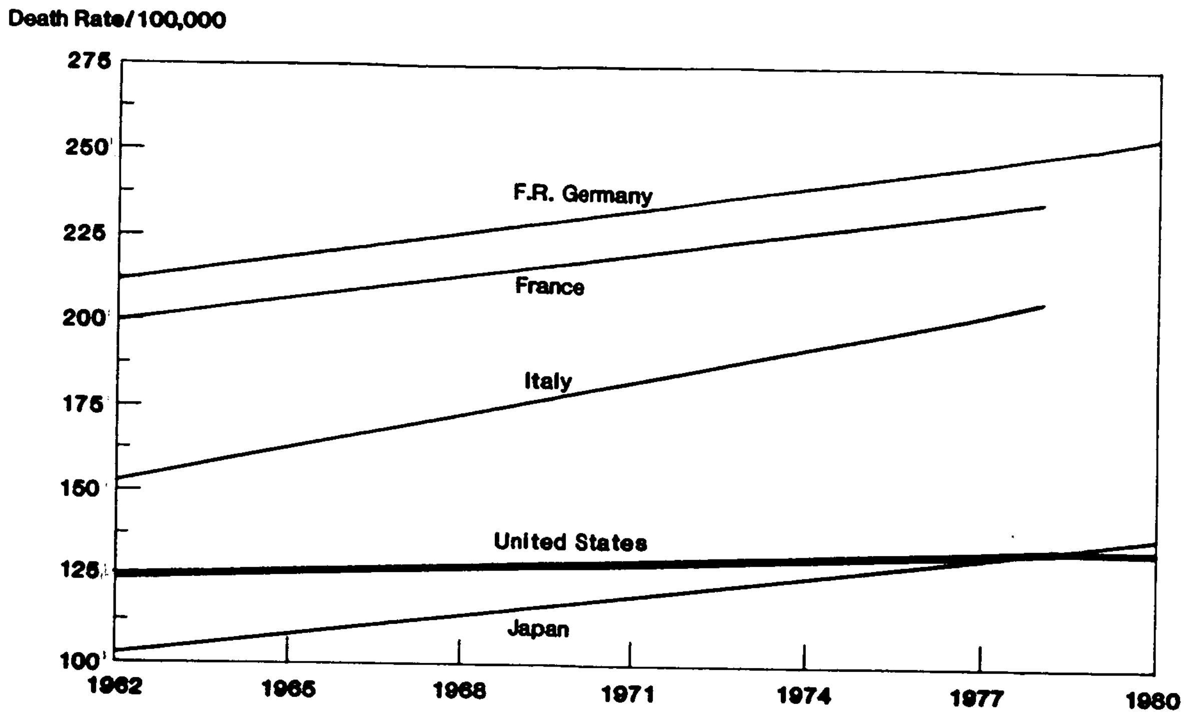
The U.S. has historically maintained a lead in controlling pathogenic diseases, Figure 3-3.

With respect to control of the two principal organic dysfunctions, cancer and heart disease, Figures 3-4 and 3-5 show the U.S. to be significantly ahead, although only slightly ahead of the nearest runner-up, Japan.

The steady decline in deaths from cancer and heart disease in the U.S. is attributed, by the experts we consulted, to improved early detection, diagnostic care and new treatment technologies. Advanced technologies--such as lasers, microsurgery, implants, radiation, chemotherapy and applications of microelectronics--are not as extensively available in most other developed countries.

An indicator of increased life expectancy is shown in Table 3-1. These data show a marked trend towards increased longevity in all nations, with the U.S among the leading nations.

Another indicator of quality, length of the educational curriculum for primary medical care personnel (doctors and nurses), appears to be approximately equivalent in the U.S. and



Malignant neoplasms include all cancers identified for the year data was obtained. New methodologies may account for rate increases.

Figure 3-4. Malignant Neoplasms

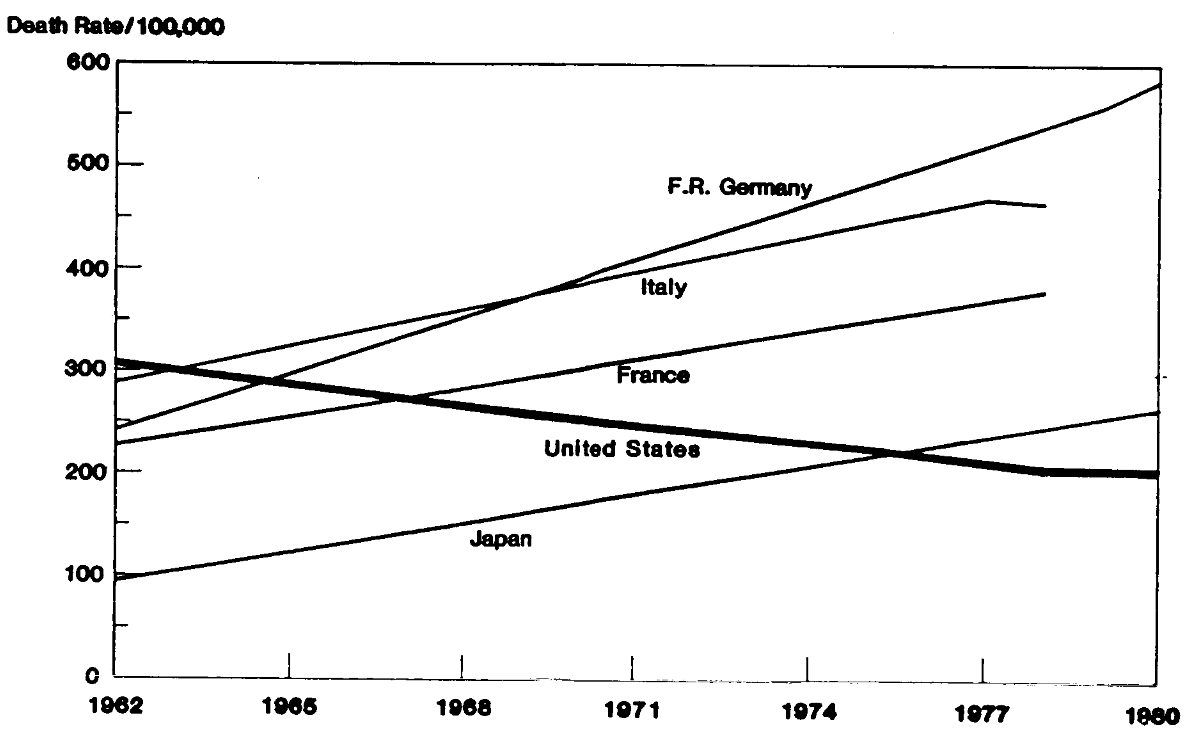


Figure 3-5. Circulatory and Heart Disease

TABLE 3-1

CONTINUED LIFE EXPECTANCY IN YEARS
AT A GIVEN AGE, BY SEX

COUNTRY	SEX	AGE IN YEARS 25	35	45	55	65	75
U.S.	M	47.0	37.8	28.9	20.8	14.1	8.9
(1978)	F	54.1	44.5	35.2	26.5	18.6	11.8
JAPAN	M	50.0	40.5	31.2	22.6	14.8	8.6
(1980)	F	55.2	45.4	35.9	26.7	18.0	10.6
FRANCE	M	47.4	38.0	29.0	21.0	14.1	8.9
(1978)	F	55.0	45.4	36.0	27.0	18.5	11.1
F.R. GERMANY	M	46.9	37.5	28.4	20.1	13.0	7.6
(1979)	F	53.0	43.3	33.9	24.9	16.7	9.7
ITALY	M	47.8	38.2	29.0	20.7	13.6	8.0
(1977)	F	53.7	43.9	34.4	25.3	16.9	9.8

other developed nations--12 to 13 years of primary education, followed by 6 to 8 years of college for physicians and 4 years of college for clinical nurses. No standardized measure of the relative quality of the educational curricula is available. However, the fact that the number of foreign physician trainees in the U.S. far exceeds the number of American trainees abroad, suggests the superiority of the U.S. medical training.

Quantity of Health Care

One measure of the ability of primary health care personnel to satisfy health needs is the ratio of physicians and nurses to population. Table 3-2 shows that the U.S. clearly exceeds Japan and Italy.

In terms of the number of hospitals and hospital beds per unit population, while U.S. resources appear to be fewer, the occupancy rate in U.S. short-stay hospitals is greater, Table 3-2. It appears that the U.S. exploits its health facilities more efficiently.

Productivity of Health Care

Table 3-3 compares one of the significant indicators of productivity, average length of patient hospital stay. In this respect, U.S. productivity appears to exceed that of Japan and Italy.

Equity of Health Care Distribution

This refers to the individual's ability to afford health care. Historically, the burden of paying for medical care has rested with the individual. Within the last 50 years, however, increasingly larger proportions of the costs of health care have been provided by national governments and private insurers. Among industrialized nations, this has resulted in publicly

TABLE 3-2

COMPARISON OF HEALTH CARE RESOURCES, 1980

INDICATOR	U.S.	JAPAN	ITALY
TOTAL HOSPITALS/100,000	3	8	3
TOTAL BEDS/100,000	591	1,127	964
SHORT-STAY HOSPITALS/ 100,000[a]	3	7	3
SHORT-STAY BEDS/100,000	474	780	778
OCCUPANCY RATE (%)	75.6	N.A.	69.7
PHYSICIANS/100,000 POPULATION	201	134	115
NURSES/100,000 POPULATION	511	422	321

[a] SHORT-STAY HOSPITALS ARE ALL HOSPITALS EXCLUDING TUBERCULOSIS SANITARIUMS, MENTAL INSTITUTIONS, LEPROSARIUMS AND MAINTENANCE CARE FACILITIES.

SOURCES: U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
ANNUARIO STATISTICO ITALIANO
MINISTRY OF HEALTH AND WELFARE, JAPAN

TABLE 3-3

NEW ADMISSIONS TO SHORT-STAY GENERAL SERVICE HOSPITALS, 1980

	U.S.	ITALY	JAPAN
TOTAL ADMISSIONS (MILLION)	38.1	9.9	8.6
PERCENT OF POPULATION	16.8	17.6	7.4
RATE PER 100,000	16,750	17,560	7,360
AVERAGE LENGTH OF STAY (DAYS)	7.8	11.8	37.3
RELATIVE PRODUCTIVITY	**1**	**0.66**	**0.21**

SOURCES: U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
ANNUARIO STATISTICO ITALIANO
MINISTRY OF HEALTH AND WELFARE, JAPAN

financed and subsidized health care systems tailored to each nation's needs and culture.

In the U.S., most health care financing is provided through private health insurance, most often supplied by employers. Employees pay a portion of the cost, on the average, about 20%.

Federally subsidized health care is reserved for persons aged 65 and over and the medically indigent, the latter falling below defined minimum income levels. In 1980, the indigent income level was $4,190 for individuals and $8,414 for a family of four. Federally financed health care subsidies are augmented by mandatory contributions (2.6% of employee earnings), shared by employees and employers.

Financing of health care in Japan and Italy differs from that of the U.S. in two ways:

1) All persons in Japan and Italy are covered, primarily through government funding.

2) The Japanese and Italian systems operate primarily through government-owned insurance companies; the governments also provide subsidies to approved private insurers. By contrast, U.S. insurance companies are nonsubsidized, private corporations.

Table 3-4 summarizes key characteristics of government-financed health care programs in the U.S., Italy and Japan.

Table 3-5 shows government expenditures in the U.S., Japan, and Italy for financing health care. While caution should be exerted in comparing the data because of differing health care costs, the significance of the Table is in the relative distribution of expenditures. Italy expends almost twice as much on health care financing as a percentage of GNP as the U.S.,

TABLE 3-4

GOVERNMENT PROGRAMS FOR MEDICAL CARE

CHARACTERISTICS	U.S.	JAPAN	ITALY
COVERED POPULATION	• MEDICAL INDIGENTS • PERSONS 65 AND OVER	ALL RESIDENTS	ALL RESIDENTS
GOVERNMENT CONTRIBUTIONS	COST OF ADMINISTRATION AND BALANCE OF MEDICAL EXPENSES	45% OF SUBSIDY TO APPROVED INSURERS AND ADMIN. COSTS[a]	VARIOUS SUBSIDIES[a]
TAX CONTRIBUTIONS			
• EMPLOYER	1.3% OF PAYROLL	4.2% OF PAYROLL	10-15% OF PAYROLL
• EMPLOYEE	1.3% OF EARNINGS	4.2% OF EARNINGS	0.3% OF EARNINGS
COVERAGE	VARIES BY STATE. GENERALLY ALL EXPENSES EXCEPT THE FIRST $200 AND $51 PER DAY FOR 30 DAYS AFTER AN INTIAL 60-DAY PERIOD	ALL MEDICAL SERVICES. PATIENT LIABILITY LIMITED TO 20-30% OF COSTS DEPENDDENT UPON CARE RECEIVED	ALL MEDICAL SERVICES. LIABILITY UNKNOWN
DEPENDENTS OF COVERED INDIVIDUAL	DEPENDENT CHILDREN OF THE MEDICALLY INDIGENT	SAME AS COVERED INDIVIDUAL	SAME AS COVERED INDIVIDUAL
ADMINISTERING AGENCIES	DEPARTMENT OF HEALTH AND HUMAN SERVICES	MINISTRY OF HEALTH AND WELFARE	MINISTRY OF LABOR AND SOCIAL WELFARE
	SOCIAL SECURITY ADMINISTRATION	SOCIAL INSURANCE AGENCY	NATIONAL SOCIAL INSURANCE INSTITUTE
	HEALTH CARE FINANCING ADMINISTRATION	NATIONAL HEALTH INSURANCE SOCIETIES (SUBSIDIZED)	

[a] THE JAPANESE GOVERNMENT PROVIDES 45% OF THE FUNDING FOR GOVERNMENT APPROVED PRIVATE INSURANCE COMPANIES AS WELL AS THE COST OF ADMINISTERING INSURANCE BENEFITS. IN ITALY, SUBSIDIES VARY WITH THE TYPE OF INSURANCE COMPANY, USUALLY BY OCCUPATION, WITH NO FIXED PERCENTAGE ASSIGNED. IN BOTH COUNTRIES INSURING AGENCIES MUST BE APPROVED BY THE GOVERNMENT TO QUALIFY FOR A SUBSIDY.

SOURCE: U.S. DEPARTMENT OF HEALTH AND HUMAN RESOURCES, RESEARCH REPORT NO. 58

TABLE 3-5

GOVERNMENT EXPENDITURES FOR HEALTH CARE

	U.S.	JAPAN	ITALY
TOTAL EXPENDITURES (1972 MILLION $)	$59,015	$12,718	$12,965
PER CAPITA	$259	$108	$230
AS PERCENT OF GNP	4%	3.6%	7.3%

SOURCES: U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, 1982
MINISTRY OF HEALTH AND WELFARE FOR JAPAN
ANNUARIO STATISTICO ITALIANO

TABLE 3-6

SOURCES OF PAYMENT FOR
MEDICAL SERVICES IN THE U.S.

	ALL SOURCES	PAYMENT BY INDIVIDUALS	PRIVATE INSURANCE	GOVERNMENT	OTHER
PERCENT OF TOTAL 1950	100.0	65.6	9.1	22.4	2.9
PERCENT OF TOTAL 1980	100.0	32.9	26.0	39.7	1.4
1980 MILLION $ (CONSTANT 1972 $)	122,800	40,420	31,900	48,800	1,700

SOURCE: U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, 1982 although per capita expenditures are comparable. Japan spends about the same percentage of GNP as the U.S., but less per capita than either the U.S. or Italy.

While per capita expenditures in Italy and Japan cover the entire population, U.S. expenditures, though expressed in per capita aliquots, are confined primarily to the medically indigent and elderly. Thus, while the U.S. federal government contributes almost half of the national expenditures for financing health care, a major burden falls on individuals and insurers, Table 3-6. The U.S. emphasis on health care financing by individuals suggests possible inequities deriving from the poorer individual's inability to pay insurance premiums.

3.2.2 HEALTH CARE TECHNOLOGY

Historically, the U.S. health care system has encouraged advanced medical technologies. Table 3-7 lists key technologies currently being introduced. As indicated, they draw on advances from other fields, such as microcomputers, lasers, new materials. The technologies shown in the Table fall into three principal categories:

- Noninvasive diagnostics
- Surgical and curative technologies
- Prosthetics

Noninvasive Diagnostic Techniques

Computer Axial Tomography (CAT) and ultrasound scanners are two of the principal diagnostic technologies being developed for the short and medium-term.

TABLE 3-7

PRINCIPAL NEAR AND MEDIUM-TERM TECHNOLOGIES ENTERING THE HEALTH CARE INDUSTRY

TECHNOLOGY	DESCRIPTION
NONINVASIVE DIAGNOSTICS	
• COMPUTER AXIAL TOMOGRAPHY (CAT, CT)	COMPUTER ENHANCEMENT OF X-RAY IMAGES PROVIDING BETTER DIAGNOSTIC INFORMATION.
• NUCLEAR MAGNETIC RESONANCE (NMR)	ALLOWS TOMOGRAPHIC SCANNING WITHOUT IONIZING RADIATION THEREFORE REDUCING PATIENT RISK. PRODUCES CHEMICAL AS WELL AS DIAGNOSTIC DATA. PRODUCES UNOBSTRUCTED IMAGES IN BOTH CROSS-SECTION AND SAGITTAL PLANE VIEWS.
• POSITRON EMISSION TOMOGRAPHY (PET)	DEVELOPED IN THE 1970s. UTILIZES ISOTOPE INJECTION COMBINED WITH COMPUTER ASSISTANCE TO MEASURE AND VISUALIZE HUMAN METABOLISM. IMPROVED VERSIONS CAPABLE OF DETECTING RAPID CHANGES IN METABOLISM.
• DIGITAL SUBSTRUCTION ANGIOGRAPHIC (CT)	INCORPORATES FLUOROSCOPY AND ANGIOGRAPHY INTO CT SCANNING TO PROVIDE MORE DIAGNOSTIC INFORMATION IN A SINGLE SCAN.
• ULTRASOUND SCANNER (US)	PRODUCES COMPUTER ASSISTED HIGH RESOLUTION, REAL-TIME IMAGES. NEW TECHNIQUES ALLOW DETECTION OF CHANGES IN TISSUE PROPERTIES INDICATING SPECIFIC DISEASES.
• HELIUM BEAM RADIATION	CAPABLE OF DELIVERING 8,000RADS TO A TUMOR WITH PRECISIONS SUCH THAT TISSUE 3mm FROM POINT OF FOCUS IS UNAFFECTED.
• COLD-FIRE LASER SURGERY	EXCISION OF ABNORMAL GROWTHS, SELF-CAUTERIZATION OF INCISIONS, DESTRUCTION OF CANCEROUS CELLS. ADAPTABLE TO OUTPATIENT TREATMENT. IN ADDITION, PROVIDES A FINER CUTTING LINE, USED NOW AS PHOTOCOAGULATOR FOR REATTACHMENTS OF OPTIC NERVE TO RETINA. ULTRAVIOLET LASERS (UV) OR COLD LASERS DISRUPT THE BINDING CELL ENERGY WITHOUT AFFECTING NEARBY CELLS.
• MICROWAVE SCALPEL	HIGH FREQUENCY VERSION OF RADIO FREQUENCY DEVICES WITH LESS CELL DISRUPTION.
• PUMP APHERESIS	WILL DRAW, SEPARATE, TREAT, FILTER AND RETURN THE BLOOD. CURRENTLY UNDER RESEARCH WITH APLASTIC ANEMIA AND LUPUS.
• ENDOSCOPICS	USING FIBER OPTICS, FOR ILLUMINATION, VIEWING, SALINIZATION, OR FLUID/PARTICLE WITHDRAWAL IN BIOPSY AND MICROSURGERY. REDUCES PERFORMANCE TIME AND COSTS, HOSPITAL STAYS AND LOSS OF WORK TIME.
a) TRANSDUCER HEADS	MEASURE CHEMICAL IMBALANCES, CELLULAR FLUIDS, AND CHEMICAL INDICATORS. WOULD ALLOW PARALLEL ENDOSCOPIC MICROSURGERY AND IMMEDIATE DIAGNOSIS AND REMOVAL OF DISEASED/DAMAGED CELLS. WOULD REDUCE MENTAL/PHYSICAL TRAUMA, DECREASE RISK OF INFECTION, ELIMINATE NEED FOR TRANSFUSIONS, REDUCE HOSPITAL STAYS.

APPROXIMATE ERA OF SIGNIFICANT DIFFUSION

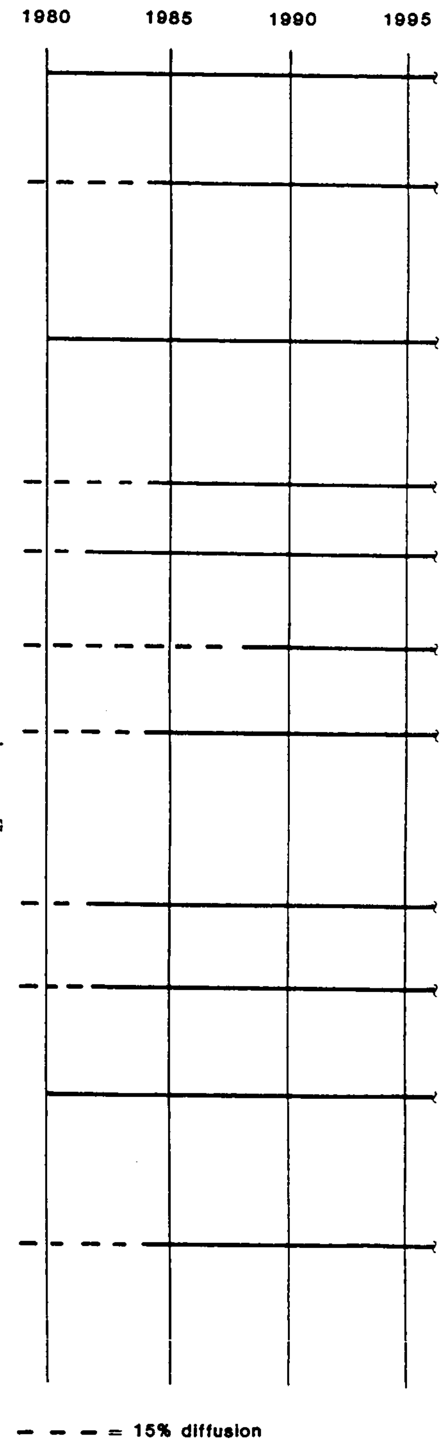
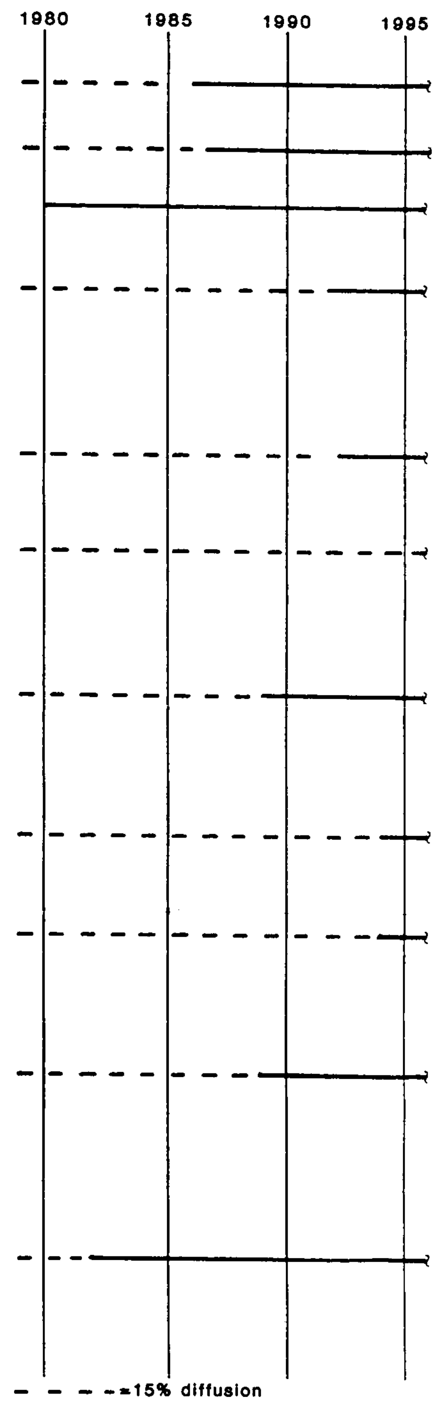


TABLE 3-7 CONT'D

b) SUTURING HEADS	BIODEGRADABLE SNAPRINGS ATTACHED IN SUTURING HEAD TO "CLAMP" TISSUE TOGETHER.	
c) ADHESIVE AUGMENTED PLASTIC SUTURES	BIODEGRADABLE, AUGMENTS OR SUBSTITUTES FOR PLASTIC SUTURES.	
• INTRA-ARTERY BALLOONS	REDUCES THE NEED TO LIGATE VESSELS OR PROVIDE REPLACEMENT BLOOD.	
• COMPUTERIZED ANESTHESIOLOGY	PROVIDES ANESTHESIA AND ALSO MONITORS VITAL SIGNS, BLOOD GASES, AIRWAY RESISTANCE AND INDUCED GAS CONCENTRATION.	
<u>NEW MATERIALS PROSTHESIS</u>		
• ARTIFICIAL ORGAN TECHNOLOGY— ARTIFICIAL HEART	NEW NONREACTIVE MATERIALS AND DEVELOPMENT OF MINIATURIZED PROPULSION SYSTEMS AND POWER SOURCES.	
• ARTIFICIAL LIMB PROSTHESIS	ADVANCES IN SENSORS, MINIATURE MOTORS, POWER SUPPLIES AND LIGHT ALLOY MATERIALS WILL IMPROVE UTILITY, ALLOW FINE MANIPULATIONS AND PRODUCE AESTHETICALLY ENHANCED PROSTHETICS.	
• ARTIFICIAL SKIN	CHEMICALLY SYNTHESIZED FROM ANIMAL HIDES, PROVIDES AN ORGANIC BUT BIOLOGICALLY INERT COVER FOR BURN VICTIMS. IS ABSORBED BY THE BODY DURING THE HEALING PROCESS. REDUCES SCARRING.	
• ARTIFICIAL BLOOD	TEFLON-BASED WITH AN ARTIFICIAL HEMOGLOBIN, CAN BE USED IN TRANSFUSIONS WITHOUT NECESSITATING CROSS-MATCHING.	
• ARTIFICIAL BODY COMPONENTS	THROUGH GENETIC AND MOLECULAR ENGINEERING. TREATMENTS FOR DEGENERATIVE DISEASES, OSTEOPOROSIS AND REPLACEMENT PROSTHESIS. BY COMPUTER DESIGN, WILL PROMOTE BONY IN-GROWTHS, AND JOINT REMODELING.	
• NEUROMUSCULAR STIMULATORS	REPLICATION OF NERVE CELLS OR SYNTHETIC NERVE CELLS TO COMPLEMENT EXISTING CELLS. IMPLANTATION OF "JUMP WIRES" TO REPAIR FAULTY NEURAL CONDUCTION PATHWAYS (WITH OUTSIDE-BODY POWER SOURCE). TIMING UNITS OR BIOLOGICAL SWITCHES WILL PERIODICALLY POLARIZE THEMSELVES.	
• LIMB TRANSPLANTS	COMBINING JOINT RECONSTRUCTION, NERVE JOINING, BIOCHEMICAL OR DRUG TREATMENT, CLONAL ANTIBODIES, TO ELIMINATE THE NEED FOR PROSTHESIS TO REPLACE LIMBS AND DIGITS.	



Although clinically impressive, their long-term practical benefits hinge on reducing costs and on increasing the precision of early diagnosis. Application of these noninvasive diagnostic techniques is currently constrained by the state-of-the-art of data interpretation, i.e., the ability to more accurately correlate raw measurements with disease or disfunction.

As data interpretation techniques improve, noninvasive diagnostic technology could increasingly replace exploratory surgical procedures. Such improvements are largely dependent on higher CAT and ultrasound resolution techniques. Newer sensors, such as nuclear magnetic resonance tomographers, may also supply needed improvements.

Surgical and Curative Technologies

Medical researchers have long sought methods and devices to make surgical procedures more effective and less traumatizing.

Two promising technologies, helium beam radiation and cold fire laser surgery, are presently undergoing experimental testing, Table 3-7. Coupled with advanced diagnostics, these technologies may be expected to become important in cancer surgery and tumor therapy by the mid-1990s. The advantage of helium beam technology is its ability to deliver high levels of radiation to small areas, as opposed to current methods requiring generalized radiation exposure with increased patient risk. Cold fire laser surgery using fiber optics can vaporize cancerous cells, leaving no residue to promote metastasis. This process substantially reduces the risk of tumor recurrence.

Curative technologies of interest include techniques that facilitate blood cleansing operations that reduce the need for hospital visits after surgery. Pump apheresis equipment, which provides cleansing of blood or body fluids outside the body, shows great promise for miniaturization. An implanted pump could accommodate continuous site-specific chemotherapy or hormone delivery and sustained release of supplementary enzymes. This would greatly reduce the need for daily insulin injections by diabetics and minimize side-effects in chemotherapy cancer patients, resulting from treating the whole body rather than specific cancerous loci.

Endoscopics show promise of reducing the size of incisions and the complexity of biopsy operations. Use of fiber optics for illuminating viewing sites makes microincisions possible, resulting in less debilitating surgery. Smaller exploratory operations may also lead to cost reductions and efficiency increases.

Use of computers to monitor a patient's vital signs and to administer anesthesia is likely to become widespread. This could reduce medical costs by increasing the productivity of hospital personnel.

Prosthetics

Prosthetic technology has been evolving for many years. Formerly, prosthesis was limited to devices such as "peg legs," hooks for hands, crutches, wheelchairs, litters. Today, prosthetic technology includes artificial limbs, hearing aids, motorized wheelchairs. Recent experimental prosthetic devices include artificial organs, skin and blood.

A major constraint affecting the pace of these developments is the requirement of government agencies to review human experimental results prior to certification. Medical products, drugs and devices are subject to Food and Drug Administration regulations. Approval entails two major testing stages, normally requiring seven to ten years to complete. Currently, costs of such testing in the U.S. exceeds $1 billion per year.

Our review of the prosthetics field indicates several needs addressable by advanced technologies, similar to those we have derived (in Chapter 2) for supporting long-term industrial objectives. Thus, advances in materials and robotic techniques can accelerate the introduction of new prosthetic devices. Electronic stimulation, nerve regeneration/restoration, and micro or laser surgery portend the possibility for full restoration of senses by artificial means. Artificial eyes would allow one to see dimensions, characteristics, shapes and movements; further advances would facilitate the perception of color and "real pictures" besides graphics. Artificial ears, more sensitive than hearing aids, would provide expanded hearing ranges. The sense of touch could be expanded to include color and texture; the sense of smell, to distinguish subtle variances.

Similarly, advances in pattern recognition would improve the physician's ability to interpret noninvasive imagery. "Information rationalization" technology would allow physicians to draw upon ever-growing, multidisciplinary databases to arrive at earlier, more accurate diagnoses. Improvements in "rapid learning" would enable practicing medical personnel to keep abreast of the growing state-of-the-art. These techniques may also enhance the productivity of medical personnel by shortening the time required to achieve the requisite professional skill levels.

Notwithstanding the pre-eminent position of the U.S. in the health field, the desire for ever-improved health care is a strong and continuing aspiration of the Amercian public. In view of the large, and growing, expenditure of resources which the nation devotes to health care and the prospects which technology offers, medical technology demands significant industrial and government support.

Accordingly, we identify **medical technology** as a leapfrog technology thrust candidate, supplementing the nine "pervasive" technologies identified in Chapter 2.

3.3 SECURITY

Security connotes the desire to be free from danger, fear, anxiety, want or deprivation. Recognized by the framers of the Constitution, the Preamble cites "to promote domestic tranquility" to be one of the government's paramount aims.

Primarily concerned with promoting law and order among their citizens, governments have also sought to alleviate the effects of deleterious natural events. Jefferson implied this responsibility in the statement that one of the government's responsibilities is the "erection of lighthouses." As technology evolved, protection from untoward natural events became the principal objective of such agencies as the Corps of Engineers, NOAA, USDA's Forest Service, FEMA.

Man has always aspired to financial security. Fulfillment in developed countries was made possible by the growth in wealth resulting from the industrial revolution.

In identifying potential leapfrog technologies that support the security area, we followed a procedure similar to that described in Section 3.2 for the health field:

- We categorized the field into its principal elements, see Figure 3-6, integrating definitions and classifications in use by U.S. and international agencies, e.g., FBI, Interpol, OECD. As indicated, under "conflict" the element "international" subsumes military activities: These were excluded from our analysis.

- We compared the "status" of U.S. security elements with their historical evolution and with the equivalent posture of other developed countries. As examples, Figure 3-7 compares death rates from motor vehicle and other accidents; it also depicts trends in crimes.

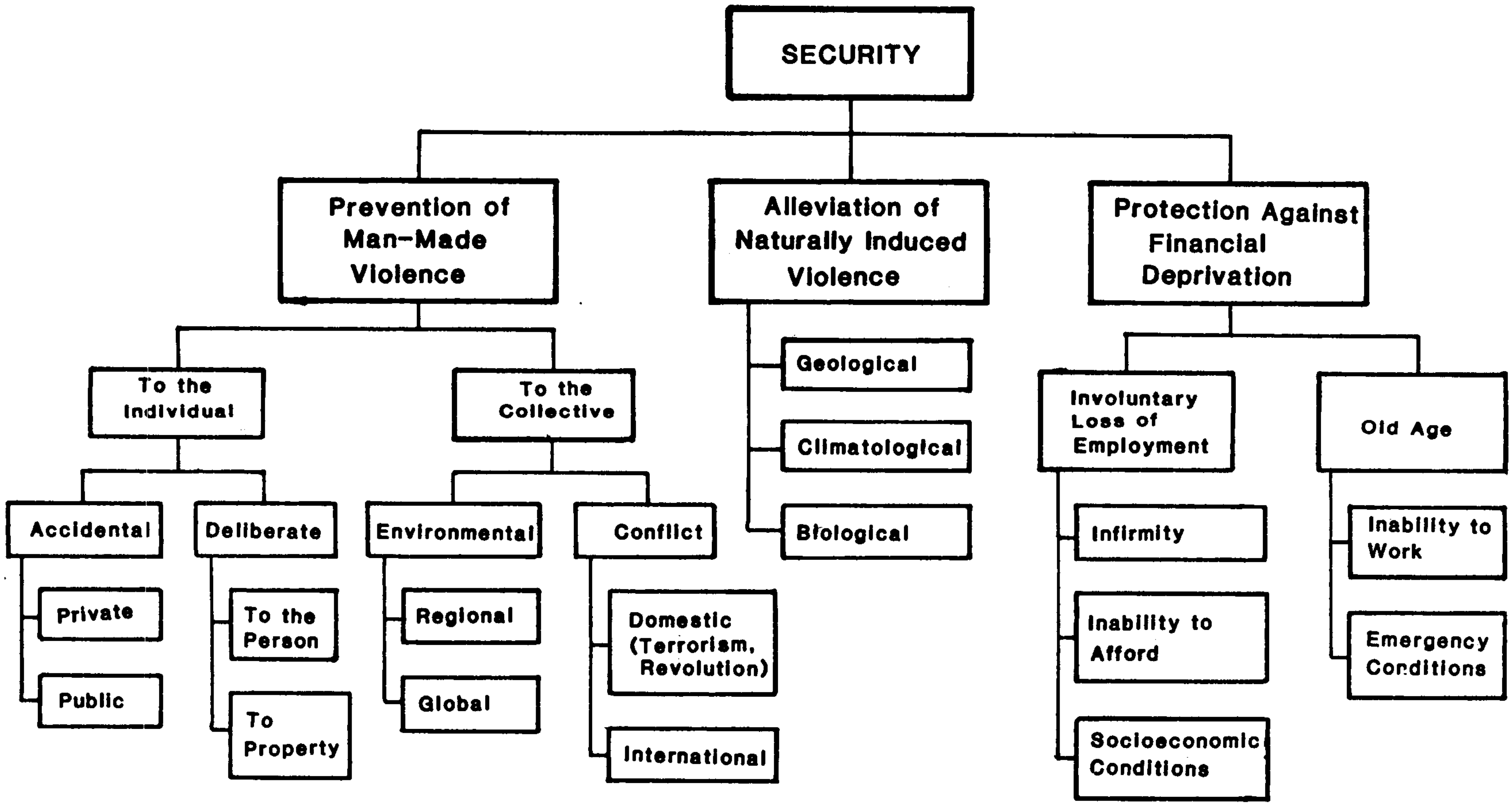


Figure 3-6. Structure of Security Aspirations

Table 3-8 compares trends in control of major air pollutant emissions. We drew on these and 44 other comparisons (described in Volume III, Section C.2) to identify "needs" requiring improved technological solutions.

- We examined the state-of-the-art of the relevant technologies, and the near and medium term improvements "coming down the pike." From this review, we identified long-term technology requirements.

Our analysis is detailed in Volume III, Section C.2. Key technological developments for enhancing individual and societal security are summarized in Table 3-9. These technologies fall into the areas of:

- Detection Technology,
- Enforcement,
- Forensic Technology,
- Societal Techniques.

As regards alleviation of climatological damage, the technological emphasis is on monitoring and prediction rather than on control. Spotting of severe weather events such as tornadoes have been based on visual sightings, leaving little time to evacuate or prepare. The National Weather Service is anticipating near-term use of a Doppler radar system (NEXRAD) that would provide warning information well in advance of actual occurrences. Other advanced technologies include use of lasers (lidar) and sound waves for probing the atmosphere to test stability parameters, wind profiles, and temperature gradients. In addition, refinements in satellite imagery techniques are expected to provide finer, more detailed and widespread data for mesoscale modeling and forecasting.

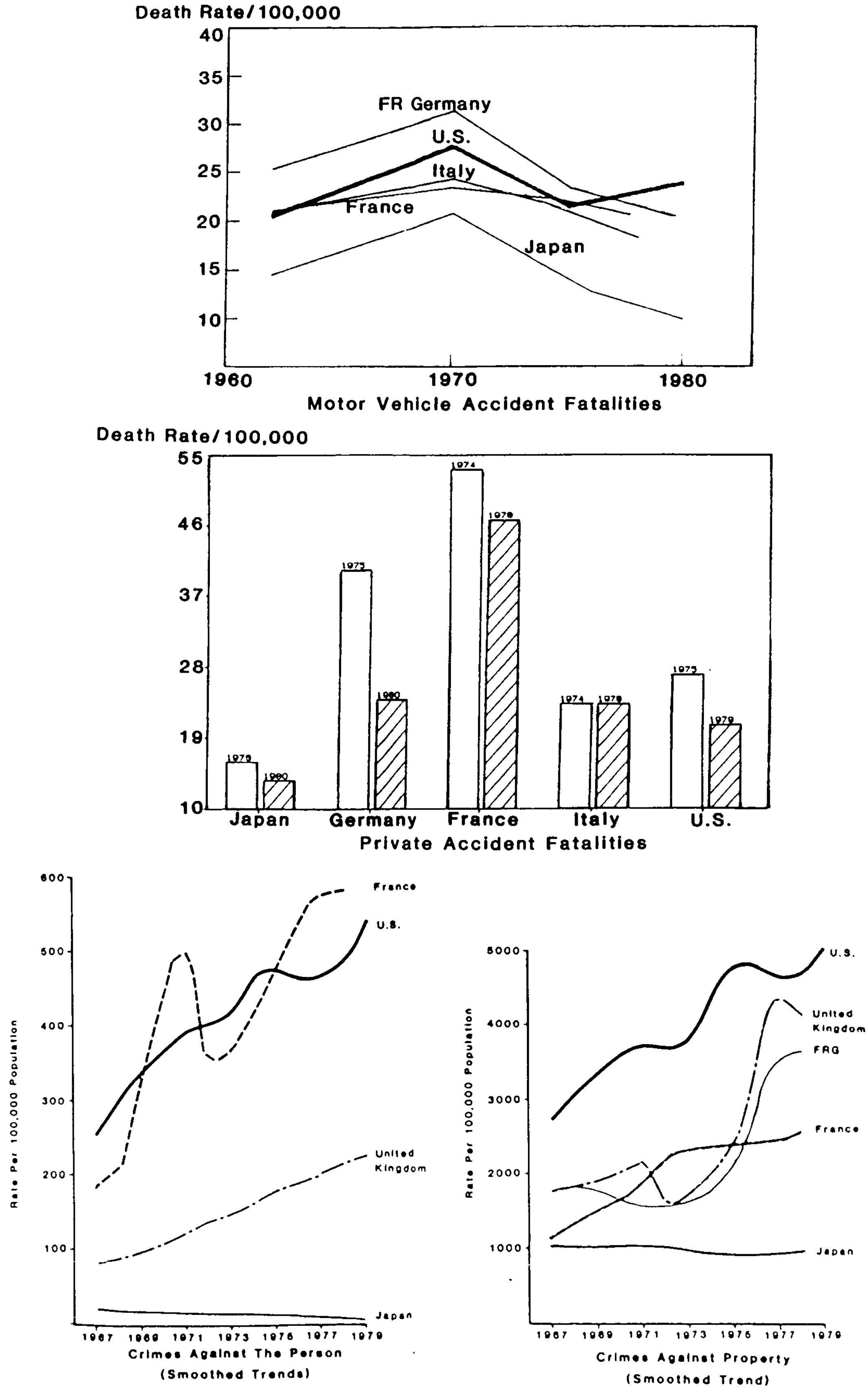


Figure 3-7. Comparative Trend of Man-Made Violence

TABLE 3-8

EMMISSIONS OF MAJOR AIR POLLUTANTS, TRENDS 1965-1975

EMISSION TRENDS
INDEX: 1970 = 100

	PARTICULATES			SO_2			NO_x			CO			HC		
	1965	1970	1975	1965	1970	1975	1965	1970	1975	1965	1970	1975	1965	1970	1975
U.S.	--	100	100.6	--	100	88.3	--	100	108.8	--	100	86.1	--	100	88.2
JAPAN	--	100	--	62.0	100	52.0	48	100	107.9	--	100	--	--	100	--
ITALY	70.0	100	--	61.7	100	--	63.8	100	112.9	67.9	100	--	69.6	100	79.5
FRANCE	81.6	100	49.4	73.8	100	147.0	65.3	100	132.0	75	100	116.6	76	100	93.4
F.R. GERMANY	202.8	100	47.6	96.9	100	85.1	82.5	100	114.0	--	100	--	79.4	100	98.4

EMISSION IN TONS PER 1,000 TONS OF OIL EQUIVALENT

	PARTICULATES			SO_2			NO_x			CO			HC		
	1965	1970	1975	1965	1970	1975	1965	1970	1975	1965	1970	1975	1965	1970	1975
U.S.	--	18.5	8.5	--	18.5	15	--	13	13	--	--	51	--	--	15
JAPAN	--	18.5	--	21.6	18.5	8.3	6.7	7.5	6.9	--	--	--	--	--	--
ITALY	--	--	--	--	--	21	--	--	2.5	--	--	--	--	--	9.5
FRANCE	--	--	3.6	12	12.6	17	5.5	6.5	7.7	--	--	4.2	--	--	2.5
F.R. GERMANY	--	--	2.1	22.6	18.2	15	--	7.2	7.9	--	--	--	--	--	7.7

-- = NOT AVAILABLE

SOURCE: THE STATE OF THE ENVIRONMENT IN OECD MEMBER COUNTRIES, 1979

TABLE 3-9

PRINCIPAL TECHNOLOGICAL DEVELOPMENTS FOR INDIVIDUAL AND SOCIETAL SECURITY

TECHNOLOGY	DESCRIPTION
DETECTION TECHNOLOGY	
• AEROSOL SPRAYS	CARRIED ON A PERSON OR OBJECT. A DETONATION SYSTEM TRIGGERS A SPRAY WITH A FOUL SEMIPERMANENT ODOR ON THE ASSAILANT. ODOR CAN ONLY BE NEUTRALIZED BY SPECIAL ANTIDOTES.
• ENVIRONMENTAL CONTROL UNITS	TO REGULATE ENVIRONMENTAL CONDITIONS OF A POPULATED FACILITY OR HOME. THE BIOLOGICAL MAKEUP OF EACH ENTRANT IS ANALYZED; INTRUDERS AND NON-APPROVED PERSONS ACTIVATE SECURITY SYSTEMS AND ALARMS. DIFFERENT STANDARDS CAN BE SET FOR DIFFERENT TIMES OF DAY.
• AUDIO MEMORIZERS	INSTANT RECALL OF EMERGENCY COMMUNICATIONS TO ASSIST IN APPREHENSION OR INVESTIGATION.
• EXPLOSIVE TAGGING COMPOUNDS	THE "TAGGING" OF EXPLOSIVES WITH IDENTIFYING MATERIALS. AFTER DETONATION THE TAGGING COMPOUNDS IDENTIFY THE MAKE, MANUFACTURER AND OTHER FACTORS.
• BEHAVORIAL PATTERN RECOGNITION	USING COMBINATIONS OF PSYCHOLOGY, SOCIOLOGY, CRIMINOLOGY AND POLITICAL SCIENCES, TO PREDETERMINE OR RECOGNIZE SIMPLISTIC CHARACTERISTICS OF CRIMINALS IN VARIOUS "COMMON" OR "OUTRAGEOUS" CRIMES. IT IS HOPED TO PREVENT ACCESS TO POTENTIAL CRIME AREAS OR TO DETERMINE THE TYPE OF PERSON(S) THAT COMMITS A CRIME BY INTERPRETING THE EVIDENCE, AND APPLYING THE INFORMATION, BY DEDUCTION, IN ORDER TO NARROW OR DIRECT THE INVESTIGATION.
• AERIAL SURVEILLANCE	THE USE OF BALLOONS, BLIMPS AND LIGHTER-THAN-AIR AIRCRAFT, EITHER UNMANNED OR MANNED, TO COVER LARGE, OPEN FACILITIES TO DETECT MOVEMENT OR UNUSUAL EVENTS. THESE CAN ALSO BE USED FOR QUICK RESPONSE TO ANY INCIDENT OR QUICK RETREAT IF NEEDED.
• CAMERA SURVEILLANCE	USE OF REGULAR OR INFRARED CAMERAS FOR DETECTION AND SECURITY, EITHER FOR CONSTANT MONITORING OR ALARM TRIPPED DETECTION. WITH A POTENTIAL OF 83 TELEVISION CHANNELS AVAILABLE, JURISDICTIONS UTILIZING EXCESS CHANNELS CAN PROVIDE SECURITY AS WELL AS CONTROL PUBLIC SCHOOL ENTRY/EXIT, TRAFFIC PATTERNS, SPECIAL EVENTS AND GENERAL ACCESS. ALSO TO BE USED FOR RUMOR CONTROL AND PUBLIC INFORMATION.
• HIGH RESOLUTION/ LUMINOUS NIGHT VISION EQUIPMENT	FOR USE DURING TIMES OF LOW VISIBILITY FOR SURVEILLANCE OR SEARCH.
• HAND-HELD RADIATION DETECTORS	FOR DRUG AND CHEMICAL DETECTION IN AUTOMOBILES OR AIRCRAFT BY DENSITY ANALYSIS; NOT SAFE FOR DRUG-CARRYING PERSON.
• PORTABLE LASER FINGERPRINT	CRIME SCENE APPLICATION OF LASERS TO DETECTION SYSTEMS TO DETECT LATENT PRINTS.
• COMPUTERS	UTILIZED FOR RAPID SEARCH OF INFORMATION; AUDIO MEMORIZERS, QUICK VERIFICATION OR REPLAY OF CALLS FOR HELP; FREEING OFFICERS FOR THE FIELD.
• AUTOMATED DIGITAL AUDIO PROCESSOR	CLARIFIES VOICES BY FILTERING BACKGROUND NOISES FOR ANALYSIS IN CONJUNCTION WITH CRIMES SUCH AS KIDNAPPINGS OR BOMB THREATS.
• VIDEO DOCUMENT ANALYSIS	DETECTS ALTERATIONS TO, REPLACEMENT OF, OR SECRET NOTATIONS TO DOCUMENTS IN AUTHENTICATING, FOR- GERY OR TAMPERING.
• VOICEPRINTING	FOR IDENTIFICATION AND FILES RECORDING. SIMILAR TO FINGERPRINTING, FOOTPRINTING OR RETINAL SCANNING.
• NEUTRON BACKSCATTER	SHOOTS BEAMS OF RADIATION AT CARS, BOATS AND PLANES; MEASURES ABSORPTION AND DEFLECTION BY DRUGS.
• SPECIAL MOBILE AUTOMATED REMOTE TERMINAL (SMART) CARE	COMPUTERIZED PATROL CARS CONTAINING TERMINALS, LOGIC UNITS, REGULAR VOICE SCRAMBLE/DECODE AND DIRECT VOICE TRANSMITTERS FOR SITUATION ANALYSIS, VEHICLE IDENTIFICATION AND COMMUNICATIONS. DESIGN WILL BE LARGER INTERIORS, LIGHTWEIGHT ARMOR, AUTOMATIC BRAKING AND PERFORMANCE READOUTS, AND LIFETIME LUBRICATION.

TABLE 3-9 (CONTINUED)

• LIFE SCIENCE ANALYSIS	ANALYSIS OF TEETH, SKIN, HAIR, BLOOD, SEMINAL FLUIDS, ATMOSPHERIC CONDITIONS AND MOISTURE TO DEVELOP INFORMATION ON TYPE, VICTIM LOCATION, TIME SEQUENCING, MOVEMENT, AND OTHER DETAILS OF A CRIME SCENE OR CRIME VICTIM. IN RECURRENT CASES, USED TO DEVELOP A PROFILE OF THE CRIMINAL FOR PREVENTION AND CAPTURE OF THE PERPETRATOR. THIS AREA INCLUDES THE RECONSTRUCTION OF A BODY, FINGERPRINTING, FOOTPRINTING, BLOOD AND SEMINAL FLUID ANALYSIS AND VARIOUS TECHNIQUES TO REASSEMBLE THE CRIME, VICTIM AND CULPRIT.
• ENTRY ACCESS	LIVE FINGERPRINTS, RETINAL BLOOD VESSEL PATTERNS, FOUR FINGER LENGTH MEASURE, VOICE ACTIVATION, BRAIN WAVE PATTERNS, IDIOSYNCRACY ANALYSIS BOTH PSYCHOMETRIC AND BIOMETRIC.
<u>SOCIETAL TECHNIQUES</u>	CREATING COMMUNITY CONCERN AND SAFETY, WHILE REDUCING THE NEED FOR POLICE AND JUDICIAL INVOLVEMENT.
• COMMUNITY MEDIATION RESOLUTION CENTERS	A COMMUNITY APPOINTED GROUP TO ACT AS ARBITRATORS IN VARIOUS CONCERNS SUCH AS NOISE, CLEAN-UP AND INTERCOMMUNITY CONFLICTS.
• JUSTICE CENTERS	A COMMUNITY APPOINTED GROUP TO ACT AS JUDGES IN CASE OF MONETARY OR PHYSICAL DAMAGES TO PERSONS OR PROPERTY RATHER THAN OR PRIOR TO COURT ACTIONS. SENTENCES OF RETRIBUTION, COMMUNITY SERVICE OR OTHER PUNISHMENTS ARE DOLED OUT.
• ENVIRONMENTAL DESIGN	REDESIGN OF THE NEIGHBORHOOD BY BUSINESSES AND RESIDENTS TO DEVELOP DEFENSIBLE SPACES, CONTROLLED ACCESS, TARGET HARDENING AND SYMBOLIC BARRIERS; PROVIDE NATURAL OPEN PATHS AND SURVEILLANCE AREAS; DEVELOP NETWORK SUPPORT BY POSITIVE INFLUENCE AND TERRITORIAL REINFORCEMENT. TRAFFIC REDUCTION BY THE CHANGING OF ROADWAY AND SPEEDS TO ALLOW SAFER PEDESTRIAN MOBILITY WHILE MAINTAINING VISUAL SURVEILLANCE. THE ELIMINATION OR REMOVAL OF DETERIORATION TO PROVIDE SAFER, CLEANER INHABITATION WHILE ELIMINATING AREAS WHERE UNSAVORY CHARACTERS LOITER.
<u>ENFORCEMENT</u>	
• ROBOTICS	MECHANICAL ROBOTS DESIGNED FOR A VARIETY OF PURPOSES.
1) SECURITY PATROLS	ROBOTS EQUIPPED WITH SENSORS, CAMERAS AND OTHER DETECTION DEVICES. ABLE TO ENTER AREAS OF HIGH SECURITY, HIGH VIOLENCE OR HARMFUL TO HUMANS; CAN DETECT INTRUDERS, OR DISARM CRIMINALS WITHOUT CAUSING A LIFE-THREATENING SITUATION TO UNIFORMED SECURITY.
2) REMOTE-CONTROLLED	USED FOR BOMB LOCATION AND DIFFUSION; FACILITY ANALYSIS, ENTRY INTO AREAS FILLED WITH VOLATILE OR GASEOUS SUBSTANCES, RECONISSANCE, RESCUE, HOSTAGE NEGOTIATIONS, ETC.
• 2-WAY SMALL COMMUNICATIONS RADIO	EITHER WRIST BANDS OR MOUNTED INTO HELMETS WITH VISUAL DISPLAY.
• GAS OPERATED PISTOLS	UNDER CURRENT TESTING, NOT FINANCIALLY FEASIBLE OR SAFE; EXPECTED IN THE NEXT TEN TO 15 YEARS
• HELMETS	LIGHTWEIGHT ALL-PURPOSE PLASTIC FOR MULTIWEAR USE. WILL INCLUDE COMMUNICATIONS, GAS MASKS, VISORS AND POSSIBLY TINTED OR INFRARED LENSES.
• HANDCUFFS	LIGHTWEIGHT PLASTIC, POSSIBLY FORM-FITTING AND MORE DURABLE AS WELL AS STRONGER.
<u>FORENSIC TECHNOLOGY</u>	
• CHEMICAL INTERACTIONS FOR DETECTION OF LATENT PRINTS BY:	
1) FUMING	FUME ADHESION OR APPLYING IODINE TO AN OBJECT.
2) SPECTROSCOPIC FLORESCENCE	COMPONENTS OF FINGERPRINT ABSORB LIGHT WHICH LUMINESCE WITHIN DIFFERENT WAVE LENGTHS OF THE ULTRAVIOLET SPECTRUM.
3) ARGON-ION LASER	EMITS LIGHT TO LUMINATE FINGERPRINTS LEFT BY PERSPIRATION, BODY OIL AND FOREIGN SUBSTANCES ON THE SKIN.
• ELECTRONIC SCANNERS/ ELECTRON MICROSCOPE	TO DETECT GUNSHOT TRACES AND GUNSHOT RELATED PARTICLES AND RESIDUE.
• ELECTROPHORESIS	ANALYSIS OF BLOOD STAINS INTO TEN SEPARATE BLOOD TYPES AND CATEGORIES FOR IDENTIFICATION.
• FAMILY SUPPORT SERVICES	
1) VICTIM/WITNESS ASSISTANCE	TO SUPPORT OR AID THOSE PERSONS SUFFERING FROM TRAUMA OR POTENTIAL VIOLENCE BY PROVIDING MENTAL AND PHYSICAL ASSURANCE, SAFETY AND AID.
2) HOTLINES	COMMUNITY PHONELINES USED TO REPORT PROBLEMS AND PROMOTE AWARENESS AND SAFETY. INCLUDES DRUG, RAPE, SUICIDE AND OTHER HELP HOTLINES MANNED BY TRAINED VOLUNTEERS. REPORT PHONELINES TO COMMUNITY OR POLICE TO REPORT CRIMES, CRIMINALS, DRUG PUSHERS, PROSTITUTION, CRIME INFORMATION.
3) PATROLS	FOOT, CAR AND TENANT PATROLS SUCH AS NEIGHBORHOOD WATCH TO MAINTAIN SURVEILLANCE, PROVIDE ASSISTANCE AND REPORT PROBLEMS TO THE POLICE.

Technology for mitigating biological hazards involves both monitoring and control measures. Examples are:

- **Monitoring**--remote sensing of environmental conditions to determine when and where outbreaks of major agricultural pests may occur, so that control technologies can be applied.

- **Chemical Communication Systems**--ongoing research uses pheromones to "jam" insect communications, disrupt breeding patterns and eliminate environmental cues from host species.

- **Genetic Control**--radiation and genetic engineering is being explored to create, sterile or nonviable hybrids that will cause the population to "crash" when introduced in large numbers; and to develop more resistant plant species.

- **Species Specific Control**--work is also underway to develop specific pesticides with limited side-effects. Another area of research is biological control in which one organism is used to control another.

Our review of the security field shows that, while advanced technologies play a role in promoting improved personal and environmental security, none of the technologies is unique to the field. Rather they draw on advances in technologies developed for other appliations. The "pervasive" technology thrusts initiated to fulfill industrial needs will enable advances in fulfilling important security aspirations.

3.4 GENERAL WELL-BEING: THE PURSUIT OF HAPPINESS

We used a conceptual approach similar to that described for the health and security fields in analyzing these aspirations. Insofar as the availability of objective "hard" data, we:

- categorized the field into components,
- compared U.S. posture with that of other nations,
- utilized these comparisons to identify "shortfalls,"
- assessed the role of technology in providing remedial measures.

The results of our analysis are detailed in Volume III, Section C.3. Key conclusions are summarized following.

- The categorization of the field that we used is shown in Figure 3-8. Reflecting our review of the relevant literature and sources of data, it draws particularly on recent attempts, noted below, at quantifying political and social indicators.

- Using these indicators, notably those published in the "World Handbook of Political and Social Indicators" (Yale University Press, 1983), we confirmed that in almost every respect the U.S. clearly leads all other nations. Table 3-10 exemplifies the relative postures of U.S. and selected other nations with respect to three important indicators: political rights, civil rights, and sectoral inequality.

- Notwithstanding the "superior" U.S. position, social analysts cite a number of concerns and shortfalls requiring improvement. Those addressable by technology include:

  - Proficiency in foreign languages. Compared to other developed nations, Americans rank low in this respect;

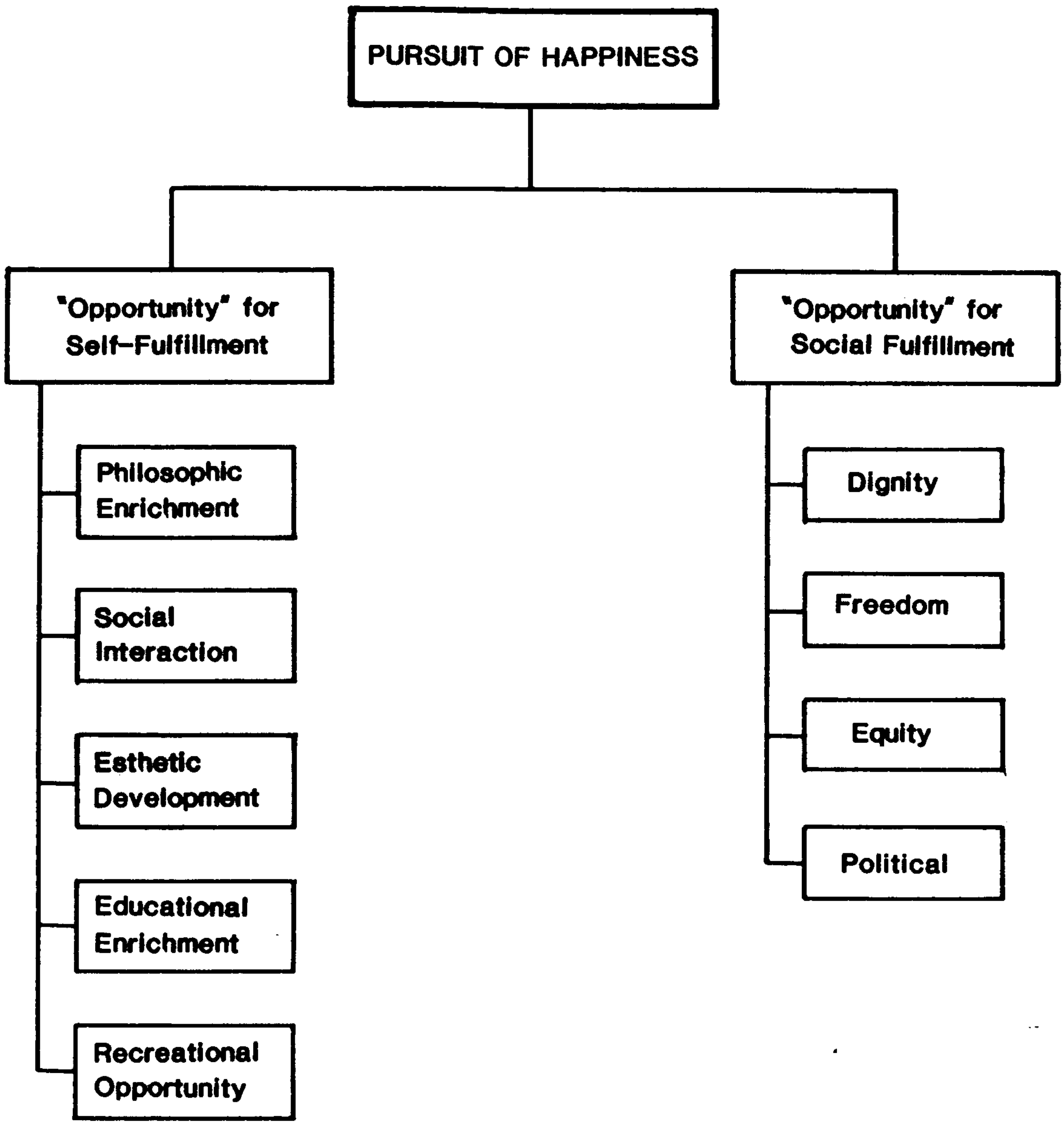


Figure 3-8. General Well-Being Components

TABLE 3-10

SELECTED SOCIETAL INDICATORS

GASTIL'S POLITICAL RIGHT INDEX

COUNTRY	1979
U.S	1
U.K.	1
SWEDEN	1
FRANCE	1
F.R. GERMANY	1
ITALY	2
JAPAN	2
INDIA	2
MEXICO	4
SAUDI ARABIA	6
U.S.S.R.	7

GASTIL'S INDEX = 1 (HIGHEST POLITICAL RIGHTS)
= 7 (LEAST POLITICAL RIGHTS)

THE POLITICAL RIGHTS INDEX IS DESIGNED TO MEASURE THE DEGREE TO WHICH CITIZENS ARE ALLOWED TO PLAY A PART IN DETERMINING WHO WILL GOVERN THE COUNTRY AND WHAT THE LAWS WILL BE, i.e., POLITICAL LIBERTY.

THE PRINCIPAL CRITERIA ARE THE DEGREE OF FREEDOM IN WHICH THE MAJORITY MAY FORM POLITICAL ASSEMBLAGES. PARTICIPATE IN GENERAL ELECTORAL PROCESSES, AND THE RIGHT TO COMPETE FOR PUBLIC OFFICES.

GASTIL'S CIVIL RIGHTS INDEX

COUNTRY	1979
U.S.	1
U.K.	1
SWEDEN	1
JAPAN	1
FRANCE	2
INDIA	2
MEXICO	4
SAUDI ARABIA	6
U.S.S.R.	6

GASTIL'S INDEX = 1 (HIGHEST CIVIL LIBERTY)
= 7 (LEAST CIVIL LIBERTY)

THE CIVIL RIGHTS INDEX IS THE BALANCE BETWEEN THE POLITICAL RIGHTS OF MAJORITIES VIS-A-VIS THE CIVIL LIBERTIES OF MINORITIES, i.e., THE RIGHTS THE INDIVIDUAL HAS VIS-A-VIS THE STATE. THE PRINCIPAL CRITERIA ARE THE DEGREE OF FREEDOM OF EXPRESSION POSSIBLE AND EVIDENT IN THE NEW MEDIA.

GINI COEFFICIENT OF SECTORAL INEQUALITY

COUNTRY	1960	1970
SAUDI ARABIA	—	70.8
MEXICO	42.8	36.2
INDIA	23.4	20.5
JAPAN	23.1	16.9
FRANCE	15.3	12.7
SWEDEN	14.7	9.7
U.K.	1.3	2.3
U.S.	3.1	1.7

THE GINI COEFFICIENT MEASURES THE DISTRIBUTION OF WEALTH ACROSS ALL ECONOMIC CLASSES OF THE SOCIETY. A GINI COEFFICIENT OF 100 INDICATES THAT ONE INDIVIDUAL CONTROLS THE WEALTH OF THE ENTIRE SOCIETY: A COEFFICIENT OF 0 INDICATES THAT THE SOCIETY'S INCOME IS DISTRIBUTED EQUALLY AMONG ALL ITS MEMBERS.

- Understanding of the culture and mores of foreign countries;

- Apparent erosion of quality standards of elementary and high school education.

- Because the elements of "pursuit of happiness" are so basic, they are affected by technological innovations across the board. These can be for better or for worse. Television, for example, while providing a new medium for entertainment, appears to have exerted a negative impact on elementary and secondary school education. Similarly, future comprehensive data banks, while offering greater access to more and more people, present the potential for infringement of privacy.

- "Pursuit of happiness" goals would be affected, presumably for the better, by the increased national wealth deriving from the enhanced productivity which the introduction of the "pervasive" advanced technologies identified in Chapter 2 could bring about.

- Several of these advanced technologies appear to address directly important social shortfalls:

- **Rapid Learning** techniques, needed for enhancing industrial training and retraining, would also directly support basic education. These techniques appear to be particularly amenable to redressing the nation's foreign language deficiency.

- **Information Rationalization** techniques, providing easier, more effective use of comprehensive, multidiscipline databases, could foster one of the basic precepts of capitalist society--"information is freedom."

- **Live Presence** communications could promote greater interchange of ideas and opinions, thereby encouraging community of interests, both domestically and with foreign nations.

CHAPTER 4

TECHNOLOGY REQUIREMENTS OF FUTURE SPACE MISSIONS

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4.0 TECHNOLOGY REQUIREMENTS OF FUTURE SPACE MISSIONS

4.1 OVERVIEW

Following the methodology depicted in Figure 1-1, this Chapter reviews the spectrum of future missions that NASA may be called upon to conduct in the early 21st century, with the aim of identifying core technologies that underlie and enable them. The analysis focuses on those "leapfrog" technology improvements that can reasonably be expected to result in **at least a half-order-of-magnitude** improvement in **mission effectiveness.** In Chapter 5 following, we compare these future space technologies to the technologies identified in Chapter 2 as pervasive to the needs of U.S. industry.

While geopolitical considerations will continue to influence the national space program, we assume here that space missions of the future will increasingly be shaped by motivations of **utility,** i.e., the provision of products and services useful to industry and the public at affordable prices. The drive for utility will extend to scientific space missions, requiring mission planners to maximize the level of scientific knowledge produced **per dollar spent.**

4.2 FUNCTIONAL CATEGORIZATION OF SPACE MISSIONS

In consonance with the utility principle, future space missions will be planned and justified on the basis of their perceived useful returns. Missions will not be justified as ends to themselves, but because they are expected to perform useful functions and achieve specified objectives.

To illustrate, consider the mission "Mars exploration." Viewed from the functional perspective, the pertinent question is: For what reason do we want to explore Mars? The motivations (other than geopolitical) could be one or a combination of the following:

- Gathering data to enhance our understanding of how the solar system was formed, and how life originated in the universe. This objective would classify the mission under the category of "scientific observations." Under the utility scenario, the mission planner would have to show that Mars provides more scientific "bang for the buck" towards achieving the scientific objectives than, say, investigating the Moon or asteroids.

- Assaying the availability, on Mars, of valuable materials, potentially mineable for subsequent return to Earth. This objective would classify the proposed mission in the category of "exploitation of space resources." The mission planner would be called upon to show that the value of the materials retrieved "pays back" the mission's cost.

- Evaluating Mars's potential as a habitat for man. This would also classify the mission under the category "exploitation of space resources"--in this case, the exploitation would occur "in situ" rather than on Earth. So much remains to be learned before human settlement of Mars becomes technically feasible, however, that we prefer to consider this type mission as falling under the category of "scientific observations." The situation would be different in the case of a proposed Lunar settlement. Because much is already known about the moon, this mission would fall within the "exploitation" category; key questions pertaining to its utility would revolve around economic value rather than technical feasibility.

Figure 4-1 depicts a framework for the functional categorization of space missions. The rows of the matrix, designated "theater," categorize the mission's "geography." The columns categorize the mission's functions. The indicated intersections

Mission Functions / Theater	Earth Resource Survey	Earth Atmosphere Observation	Commercial Communications	Terrestrial Navigation	Exploitation of Space Resources			Scientific Observations	Orbital Infra-structure	Supporting Space Transportation
					Materials	Energy	Human Habitat			
LEO	•	•	•	•	•	•	•	•	•	•
GEO	•	•	•	•	•	•		•	•	•
LUNAR					•		•	•	•	•
PLANETARY					•			•		•
TRANSPLANETARY								•		•

The indicated intersections (•) reflect the optimum theater for maximum mission utility, based upon constraints imposed by the laws of nature and upon advances possible with projected engineering state-of-the-art of 2010. For example, Earth Resources Survey from the lunar theater is not shown as a valid functional mission because the projected cost/performance of sensors is not compatible with the resolution requirements nor with cost/performance achievable from LEO and GEO.

Figure 4-1. Categorization of Space Missions Based Upon the Utility Criterion

represent our projections of the theaters that are optimal for the indicated functions. The theaters are ranked from top to bottom in terms of increasing "difficulty of achievement" or, equivalently, increasing Δv requirement. This ordering also serves to rank the missions by cost, because a mission's cost is driven by its Δv requirements. Table 4-1 shows how the **functional** categories defined here encompass and relate to the designations of space missions often used in NASA planning documents.

The findings of our analyses of the functional space mission categories shown in Figure 4-1 are detailed in Volume IV, Sections D.1 through D.8. Sections 4.3 and 4.4 following illustrate the method of analysis for two missions: **Supporting Space Transportation** and **Earth Resource Survey.** Section 4.5 summarizes the findings for all the functional mission categories.

In identifying the core technologies underlying each functional mission category, we found it useful to define several indicators of value and cost. These are:

- **Dominant utility parameter(s)**--these are the key technical characteristics of the products and services produced by the space mission: for example, ground resolution in the case of Earth Resources Survey;

- **Allowable cost threshold**--this is the cost of the products or services which have the same technical characteristics as those provided by the space mission and which are obtainable from competitive, nonspace means;

- **Uniqueness**--this is the "value" of a space-derived product that is not achievable through competitive nonspace means;

- **Opportunity cost**--this is the maximum allowable cost of the space mission, i.e., the cost at which the products

TABLE 4-1

FIT BETWEEN FUNCTIONAL AND CONVENTIONAL CATEGORIZATIONS OF SPACE MISSIONS

EARTH RESOURCES SURVEY	EARTH ATMOSPHERE OBSERVATION	COMMERCIAL COMMUNICATIONS	TERRESTRIAL NAVIGATION	MATERIALS
• LAND, OCEAN, NON-RENEWABLE RESOURCES, LAND USE SURVEY • EARTH RESOURCES DATA RELAYS	• WEATHER SATELLITES IN LEO AND GEO	• INTELSATS • DOMSATS • REGIONAL COMMUNICATIONS SATS • DATA RELAY SATS • DIRECT BROADCAST SATS • MARITIME • LAND MOBILE SATS	• TRANSIT • GLOBAL POSITIONING SYSTEM	• MATERIALS PROCESSING/ MICROGRAVITY SCIENCE • MINING OF LUNAR MATERIALS • MINING OF ASTEROIDS
ENERGY	**HUMAN HABITAT**	**SCIENTIFIC OBSERVATIONS**	**ORBITAL INFRASTRUCTURE**	**SUPPORTING SPACE TRANSPORTATION**
• SOLAR POWER SATELLITES	• EARTH ENVIRONMENT/ UPPER ATMOSPHERE/SOLAR OBSERVATIONS • LUNAR BASE	• SPACE ASTRONOMY TERRESTRIAL LIFE • PLANETARY/DEEP SPACE EXPLORATION	• LEO/GEO/CIRCUM-LUNAR SPACE STATION SYSTEMS	• ELV • OTs • LUNAR/PLANETARY TRANSFER LAUNCH VEHICLES

or services produced by the mission become competitive with the cost of other, nonspace alternatives. In the case of unique space products, the opportunity cost is the level at which the cost of the space mission equals the value of the unique products.

Not all the products of space missions can be evaluated in economic terms; the data garnered from scientific observation missions are an example. However, even for such products having "intangible" value, criteria of cost/effectiveness can be applied. For example, alternative mission implementations can be compared in terms of bits of scientific data produced per dollar spent.

4.3 SUPPORTING SPACE TRANSPORTATION

4.3.1 KEY PERFORMANCE CRITERIA

The **price/performance** of space transportation (ST) is key to the deployment of useful payloads within all space theaters. In the light of the utility and cost indicators identified above, the utility parameter of ST can be defined as the weight (kilograms) of payload placed within the target theater.

Varying with the utility of the mission, the allowable cost threshold should be commensurate with the value of the useful products provided by the payload. A general desideratum is that the cost be as **low** as possible.

We focus here upon the most demanding element of ST, the Earth surface-to-LEO leg. Earth-to-LEO propulsion systems must simultaneously provide high **thrust** and high **energy.** High thrust combined with high energy is also needed for ST systems aimed at **landing** on atmosphereless celestial bodies (where atmospheric braking cannot be employed) and at **departing** from celestial bodies having significant levels of surface gravity, e.g., Moon, Mars.

The conclusions described below apply to both Earth-to-LEO ST systems operating between space theaters in which gravity is in equilibrium, where thrust can be low, e.g., transfer from LEO to GEO. Whereas STs operating from gravity "wells" are dominated by the need for **thrust,** STs connecting gravityless theaters are driven by the **time** requirements for **transiting** between theaters.

In general, ST cost is dominated by:

- The **exchange ratio,** i.e., the lift-off weight required to place a given weight of payload in a given space theater, starting from the Earth's surface or from an intermediate station, e.g., a LEO platform;

- The cost of the **support structure** required to contain the fuel, accommodate the payload, provide the thrust, supply the required guidance and control functions.

Figure 4-2 shows representative **exchange ratios** for ST systems operating from the Earth's surface. These data are based on:

- State-of-the-art structural efficiencies (ratio of weight of fuel to fueled lift-off structure, exclusive of payload) of order 90-93%;

- State-of-the-art thruster technology (available thrust engine efficiencies of order 95%).

Table 4-2 synopsizes key **cost** parameters of current ST, in terms of dollars per kilogram of liftoff structure and dollars per kilogram of payload. These costs are exclusive of the costs of the payloads themselves and of the RDT&E effort involved in researching and developing the launch vehicle; they reflect the cost of the launch vehicle, including fuel, and the cost of the launch services.

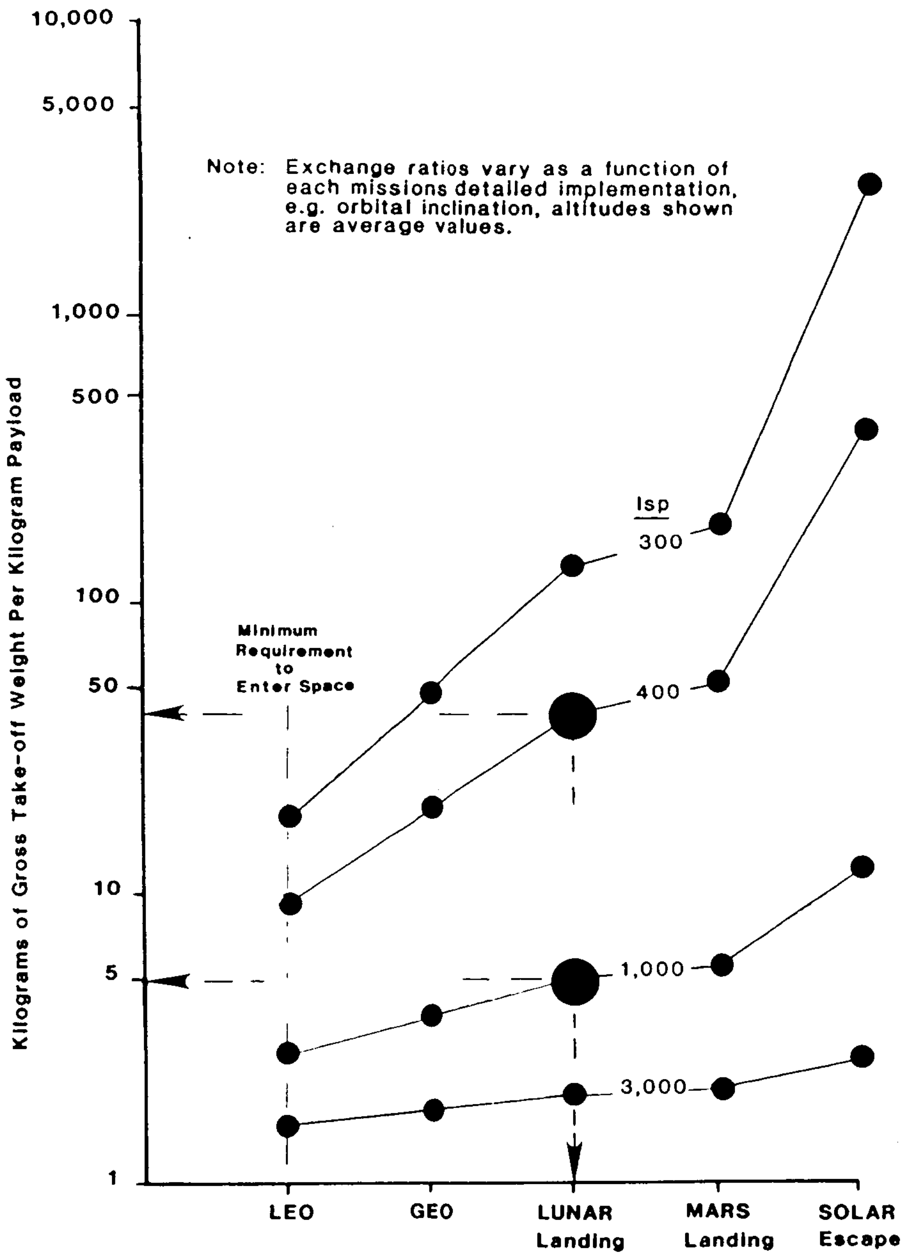


Figure 4-2. Exchange Ratios as a Function of Space Theater and Propulsion Technology

TABLE 4-2

CHARACTERISTICS OF SPACE TRANSPORTATION SYSTEMS

VEHICLE	WEIGHTS, kg		STRUCTURAL EFFICIENCY, %	COSTS, (1983 $) THOUSANDS[a]			SPECIFIC COSTS, $/kg (1983)	
	STRUCTURE	FUEL		LAUNCH VEHICLE	FUEL	LAUNCH SERVICES	LAUNCH VEHICLE STRUCTURE	TRANSPORTING PAYLOAD TO LEO[b]
SCOUT G-1	3,300	18,133	84.6	$3,400	$90	$3,250	$1,030	$38,500
ATLAS F	8,504	112,330	93	$7,760	$214	$5,059	$4,828	$16,405
ATLAS CENTAUR	13,306	134,611	91	$27,850	$884	$26,776	$2,093	$24,600
DELTA	20,464	168,829	93	$10,313	$379	$14,308	$504	$9,900
SHUTTLE COLUMBIA	284,982	1,739,857	86	SEE TABLES 4-4 AND FIGURE 4-5.				

a CY 1983--ESCALATION EXPECTED IN CY 1984

b LOW INCLINATION (>28°), LOW ALTITUDE (>500km)--INCLUDES COSTS OF VEHICLE, FUEL, LAUNCH SERVICES

Table 4-3 shows the **sensitivity** of the exchange ratio to improvements of **structural efficiency.** Comparison between Tables 4-2 and 4-3 shows that further improvement of structural efficiencies would yield only marginal benefits, i.e., increases of payload weight of, at most, another few percent.

In contrast to the ELVs, the Space Shuttle presents a somewhat different situation because of its significantly different operating characteristics, namely that the Shuttle is manned and reusable. Table 4-4 and Figure 4-3 show the Space Shuttle's costs by major elements, as a function of the number of yearly flights, and a detailed cost distribution for a 1985 manifest of 12 projected flights. As shown, Space Shuttle costs decrease significantly as the number of yearly flights increases, up to approximately 18 to 20 flights per year. At higher traffic rates, the cost reduction trend begins to flatten.

The assumption underlying the costs shown in Table 4-4 and Figure 4-3 is that the Space Shuttle's R&D and the manufacturing costs of the four orbiters are sunk and not amortized, because of their reusability. The hardware costs include only recurring costs such as those associated with the external tank. The indicated reduction in hardware costs as a function of flight frequency and time is assumed to result from learning effects.

The Space Shuttle's split between hardware and services costs is substantially similar to that for ELVs--approximately fifty-fifty. For Shuttle a larger portion of the services costs is for mission operation support, which includes flight support, research, and project management costs.

4.3.2 KEY TECHNOLOGIES

In identifying core technologies enabling advanced ST with high utility, our analysis leads to the following key findings:

TABLE 4-3

EFFECT UPON PAYLOAD WEIGHT OF INCREASING THE LAUNCH VEHICLE'S STRUCTURAL EFFICIENCY

ISP	WHEN STRUCTURAL EFFICIENCY INCREASES FROM 93% TO	PAYLOAD INCREASES BY[a]
300	95%	6.0%
	100%	16.0%
400	95%	4.0%
	100%	14.0%
500	95%	4.0%
	100%	12.0%
1,000	95%	2.5%
	100%	6.0%

[a] FOR 28°, 500 Km LEO

TABLE 4-4

PERCENTAGE DISTRIBUTION OF TOTAL COST FOR SHUTTLE FLIGHTS[a]

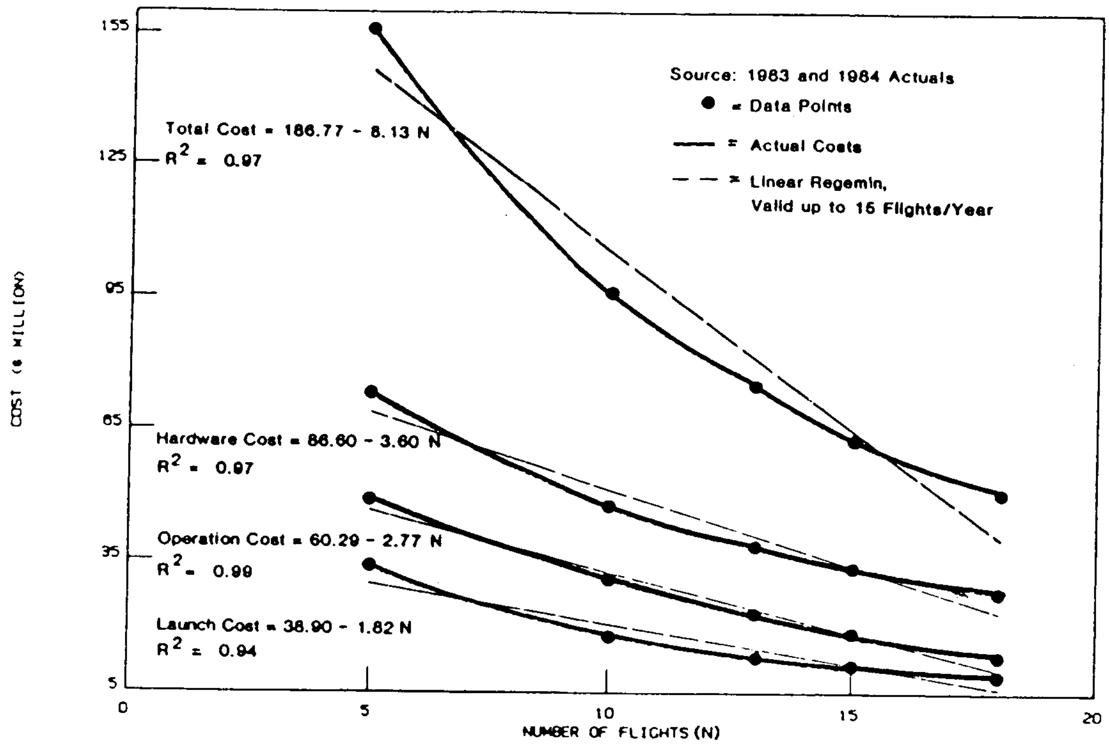
ITEM YEAR	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
HARDWARE	46.77	49.53	51.28	52.88	53.38	55.0	54.65	54.00	53.53	53.24	51.72	51.30
LAUNCH	21.26	17.76	17.50	17.79	19.75	18.6	18.62	18.89	19.09	19.21	19.83	20.00
OPERATION SUPPORT	31.25	31.87	30.42	28.52	26.16	25.6	25.92	26.29	26.56	26.72	27.59	27.83
ADMINISTRATION	0.71	0.84	0.80	0.81	0.71	0.80	0.81	0.82	0.82	0.83	0.86	0.87
NO. OF FLIGHT	5	10	13	15	18	18	18	18	18	18	18	18

[a] EXCLUSIVE OF ORBITER DEVELOPMENT AND MANUFACTURING COSTS--ORBITER ASSUMED TO BE FULLY REUSABLE

ECONOMY OF SCALE

Cost Per Shuttle Flight Versus Yearly Number of Flights

(1975 CONSTANT DOLLARS)



COST DRIVERS

Distribution of Total Shuttle Flight Cost (1985, 12 Flights/year)

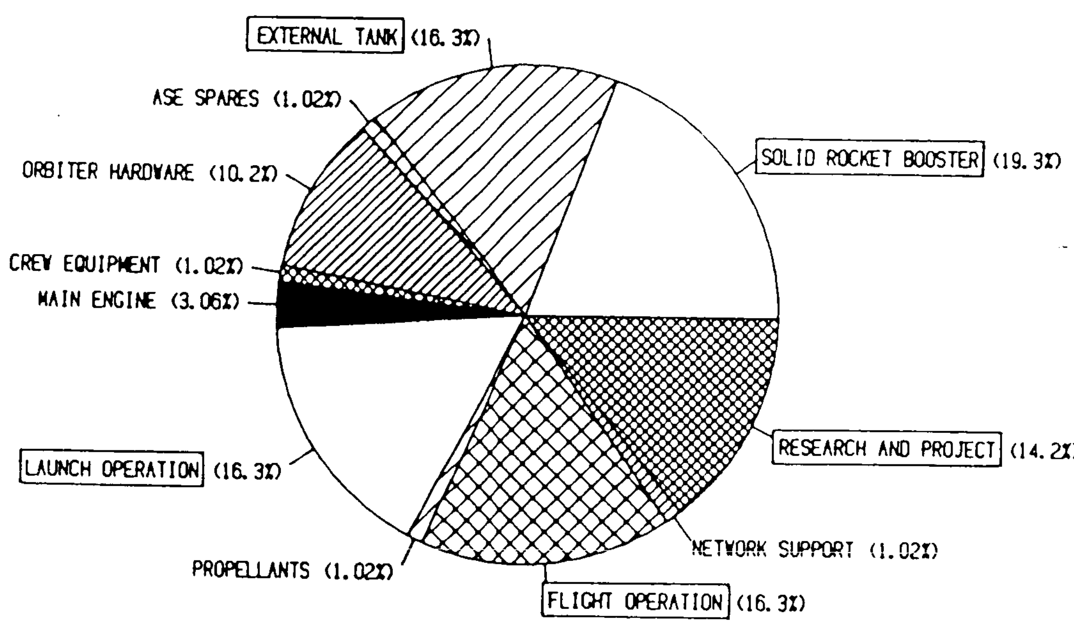


Figure 4-3. Orbiter Transportation Economics

- Further increases in **structural efficiency,** although important for other reasons, offer only modest increases in **exchange ratio.** A major impact is possible only by upgrading propellant **specific impulse.**

- The current costs of ST launch vehicle structures range from **$500** to **$2000** per kilogram. By contrast, costs of large commercial aircraft are of order **$140/kg,** including avionics and all other on-board equipment. Aircraft are reusable many times, ELVs only once.

- The cost of ST launch **services** is as high as the cost of the launch vehicle itself.

These findings suggest several techniques and technologies for achieving significant near and medium-term advances, without the need for "leapfrogging" the state-of-the-art:

- Reduction of launch vehicle **structural** costs through improved fabrication technology and new low cost-to-weight materials;

  The thrust here should not be on **lighter** structures--because the structural efficiency is already so high as to be at the point of diminishing returns--but on **less expensive** structures.

- Reduction of the cost of launch services through **automation** of service functions and use of innovative **management** techniques.

- Reduction of overall launch vehicle and spacecraft costs by trading redundancy with astronaut maintenance capability. Similar trades could optimize choice between highly reliable, costly "one shot" missions versus lower reliability, less expensive multiple missions.

With regard to the leapfrog advance--increased Isp--considerable research was invested, in the late 1950s and early 1960s, in high-energy, high-thrust propellants. The "taming" of the LOH-LOX reaction has since led to a decline in this research.

Table 4-5 lists the characteristics of potential advanced propellants drawn from a recent USAF survey of the field. Of the 26 propellant technologies reviewed by the USAF, the Table lists the six which appear most promising for practical application in the 2005-2010 era.

4.4 EARTH RESOURCES SURVEY

4.4.1 KEY PERFORMANCE CRITERIA

The object of this functional mission category is to map surface features for discovering and inventorying natural resources.

We concentrate here on observations using imaging techniques. These have been the most used from space systems. Other types of observations, important for prospecting and the inventory of natural resources, are currently performed by airborne and ground methods. These include geomagnetic, geogravitic, soil moisture measurements through use of passive microwaves. While not yet sufficiently developed to yield practical utility from space platforms, they will eventually be performable from space.

The value of the information obtained from a remote Earth observation system varies with the application to which the information is put. Experience from aircraft and space-based sys-

TABLE 4-5

ADVANCED PROPELLANTS
FOR HIGH-THRUST APPLICATIONS[a]

NOMENCLATURE/COMPOSITION	STATUS	THEORETICAL ISP, SECONDS	PRINCIPAL CHALLENGES/REQUIREMENTS	PRINCIPAL RESEARCHER(S)
FREE-RADICAL HYDROGEN	KNOWN	2,130	● VERY LOW TEMPERATURES < 0.1K ● ACHIEVEMENT OF HIGH DENSITIES	PRINCETON, MIT, JPL
METALLIC HYDROGEN	EXISTENCE POSTULATED, NEEDS DEMONSTRATION	1,700	● LOW TEMPERATURES, < 4K ● HIGH PRESSURES, 1-10M BAR ● STABLE STORAGE	AMSTERDAM UNIVERSITY
METASTABLE HELIUM	KNOWN	3,150	● SHORT LIFETIME, 2.5 HOUR THEORETICAL ● SUPPRESSION OF SPIN-ORBIT DECAY COULD INCREASE LIFETIME TO 8 YEARS	JPL
PULSE IMPLOSION FUSION	EFFECT KNOWN, NEEDS TECHNOLOGY, ENGINEERING	6,330	● RADIATOR TO REJECT HEAT ● PRACTICAL IMPLOSION METHOD ● THRUST EXHAUST SYSTEM	DOE, JPL
PULSE EXPANSION FUSION	EFFECT KNOWN, NEEDS TECHNOLOGY, ENGINEERING	> 10,000	● RADIATOR TO REJECT HEAT ● PRACTICAL MICROFUSION METHOD	DOE, JPL
OZONE-ATOMIC HYDROGEN	KNOWN	3,000	● STABLE STORAGE ● INCREASED LIFETIME	—

[a] SOURCE: U.S. AIR FORCE ROCKET PROPULSION LABORATORY, AFSTC

tems shows that the value of imaging systems is a function of three dominant parameters:[a]

- Approximately 75-80% of the value hinges on the ability to recognize shapes. The corresponding utility parameter is the system's geometric resolution.

- Approximately 20%-25% of the value depends upon the discrimination of "color." The corresponding utility parameters is the system's spectral resolution.

- Multiple observations of the same area increase the value by approximately $\sqrt{N}$, where N is the number of revisits.

The allowable cost threshold is determined by what can be accomplished, at what cost, by the most competitive alternative means, i.e., by the resolution-revisit frequency combinations achievable by conventional aircraft survey systems.

The costs of an end-to-end remote sensing system fall into three categories:

1. Costs associated with gathering the data, up to and including the generation of the raw product, e.g., film, tape;

2. Costs associated with interpreting the raw products and elaborating them into finished products, e.g., maps;

---

a "MLA Value Derived from an Analysis of National Land Mapping Activities"; ECOsystems International Inc., October 21, 1980 for NASA/GSFC.

3. Costs associated with deriving, from finished products, information needed by the final user, e.g., agricultural acreages, potential for oil and gas findings.

Category 2 and 3 costs are common to all remote sensing systems. It is only in Category 1 that a space-based system differs from its aircraft counterpart. Category 1 costs, thus, characterize the space mission's utility and drive its technology requirements.

4.4.2 DATA GATHERING FUNCTION

Representative unit costs of data gathering using conventional aircraft remote sensing systems are shown in Table 4-6.

In principle, the product of the unit costs times the area of coverage of interest (e.g., square kilometers per year) provides the cost threshold, i.e., the maximum allowable expenditure for the equivalent space system. Although a large body of literature has attempted to define the commercially practical area of coverage for an Earth resources observation satellite, the estimates range widely and a definitive assessment is not yet available.

A practical estimate of the economic value of space remote sensing can be obtained by gauging the current "mapping" business.

Mapping by federal and local civil governments and by private industry **is the primary use of remote sensing** in the U.S. today. Eighty-four percent of this mapping activity is funded by the federal government; of this, 64% is contracted to private industry. Approximately 5% of the total activity is funded by private enterprises, e.g., land developers, oil companies. Table 4-7 lists the major map products currently produced by federal, state and local agencies. Table 4-8 summarizes, by category, the quantities of mapmasters currently being produced.

TABLE 4-6

REPRESENTATIVE COSTS OF AIRBORNE REMOTE SENSING DATA GATHERING

RESOLUTION METERS	UNIT COST $/SQ. km FOR SINGLE DATA GATHERING VISITS[a]				MULTIPLYING FACTOR FOR N REVISITS[b]
	B&W	MULTISPECTRAL	THERMAL IR	SAR	
50	1	1.50	4	15	$N^{0.85}$
10	2	3	8	20	$N^{0.85}$
5	3	4	—	25	$N^{0.85}$
1	4	5	—	—	$N^{0.85}$

[a] FOR AREA COVERAGE OF 10,000 km^2. PRICES REPRESENT THE AVERAGE OF THREE COMMERCIAL QUOTES, AND ARE IN 1982 DOLLARS. THEY INCLUDE DELIVERY OF IMAGE PRODUCTS AT 60% OVERLAP. PRICES ARE SOMEWHAT LOWER FOR LARGER COVERAGES.

[b] THE MULTIPLYING FACTOR ASSUMES THAT THE REVISITS ARE COORDINATED, i.e., CONTRACTED AS A SINGLE BATCH.

TABLE 4-7

PRINCIPAL CURRENT MAP PRODUCTS

MAP PRODUCT	**PRINCIPAL PRODUCING AGENCIES**
AERONAUTICAL CHARTS	NOS
BOUNDARY MAPS	IBC, DOS
CADASTRAL MAPS	COUNTIES, STATES
CENSUS MAPS	BC
CLIMATIC MAPS	NWS
EARTHQUAKE HAZARD	USGS
FEDERAL PROPERTY MAPS	BR, FWS, FS, NPS, USGS
FLOOD PLAIN MAPS	FIA, NOS, SCS, USCE, USGS
GEOLOGIC MAPS	USGS, STATES, NOAA/EDS, BU MINES
LAND USE	NOS, USGS
HYDROGRAPHIC CHARTS	NOS, USCE, USGS
SOILS MAPS	SCS
CLIMOMETRIC MAPS	USGS
SNOW COVER MAPS	NOAA/NESS
TOPO MAPS	USGS
WATER RESOURCES MAPS	USGS
AEROPHOTOS	ASCS, BLM, DMA, FHWA
ORTHO PHOTO MAPS	USGS, NOS, BIA

TABLE 4-8

U.S. PRODUCTION OF MAP MASTERS, 1979

Numbers in Matrix Indicate the Different Types of Maps Produced

Map Type	Map Scale / Producer	1:15,000,000	1:11,000,000	1:8,000,000	1:7,500,000	1:3,168,000	1:2,500,000	1:1,000,000	1:500,000	1:250,000	1:150,000	1:125,000	1:100,000	1:63,360	1:62,500	1:50,000	1:31,680	1:30,000	1:25,000	1:24,000	1:20,000	1:15,840	Total	References
Topographic	USGS/DMA							60		90			150							2,700			3,000	8 9
Boundary	USGS							44	7							49							100	9
Cadastral	USGS/BLM																			27			27	9
Census	Bureau Census																			2,640	4,000		8,000	10
Federal Property	USGS															5				5			10	9
Orthophotomaps	USGS																		27	506			536	9
Landuse	USGS									4			6										10	9
Nautical Charts	NOAA/DMA								314		827										512		1,653	6 12 11
Bathymetric Charts	NOAA/DMA							17		347						347					116		827	12 11
Topographic-Bathymetric	NOAA/USGS																			25			25	9
Flood Plain	USGS																			50			50	9
Water Resources	USGS									3					2	8				40			53	9
Climatic	NOAA	51	51	210	45		210																567	13
Geologic Hazard	USGS															1				1			2	9
Geologic	USGS								4	11			45							47			107	9
Mineral Resource	USGS									5				16						247			268	9
Soils	USDA																1			26	68	41	136	14
Climometric	USGS															4				4			8	9
Snow Cover	NOAA/COE	56			362		304									86							800	15
Aeronautical	NOAA					48	48						95			95		4,479					4,765	6
Road	DOT/States											1,188		1,188						10,824			13,200	17
Recreation	USGS															3							3	9
Total		107	51	210	397	48	562	121	325	460	827	1,188	298	2,564	2	600	1	4,479	27	17,144	4,698	41	34,146	

Total expenditures by federal, state, local and private users in FY 1983 approximated $1,250 million (in current $). This is then the current market for mapping products. This market is forecasted to grow to $1,700 million (in 1983 $) by year 2,000 and $2,020 million by 2010[b]. This "here and now" market is much larger than the sum-total of the markets which have thus far been postulated for Landsat data, e.g., agriculture, land use, pollution mapping.

The costs of data gathering and of the other elements in the end-to-end mapping process are shown in Table 4-9. The portion attributable to the data gathering function, i.e., sensing and providing the "raw" images, is approximately 5% of the total costs. As shown, the cost of producing maps exceeds by a factor of twenty the revenue from their sales. In effect, map-making is a public service, justified by its social value rather than solely by commercial considerations.

Approximately 87% of the raw products used in mapping consist of black & white (B&W) aerial photography. For example, the Agricultural Stabilization and Conservation Service, a major producer, annually generates B&W photography covering 1,300,000 square kilometers. These are sold to map-making agencies and to the public at large.

The most significant utility parameter of B&W imagery is resolution. Table 4-10 shows the minimum resolution required for the various standard map scales.

Analysis of the mapping market shows that most of the needs for B&W are met with a ground resolution of order three to four meters. At lower resolution, the addressable market drops sharply, as shown in Figure 4-4.

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b Op. Cit.

TABLE 4-9

RELATIVE COSTS BY ACTIVITY IN THE
END-TO-END PRODUCT CHAIN OF FEDERAL CIVIL MAPPING

ACTIVITY	PERCENT OF TOTAL COST
DATA COLLECTION	5
INTERPRETATION	21
CARTOGRAPHY	44
DISTRIBUTION	5
ARCHIVING AND SALES	11
RESEARCH & DEVELOPMENT	3
TOTAL COST	100
REVENUE FROM PUBLIC SALES	5

TABLE 4-10

GROUND RESOLUTION REQUIRED AS A FUNCTION OF SCALE
FOR STANDARD MAP PRODUCTS

MAP SCALE	MINIMUM REQUIRED RESOLUTION, METERS
1: 15,000,000	3,750
1: 11,000,000	2,750
1: 8,000,000	2,000
1: 7,500,000	1,875
1: 3,168,000	792
1: 2,500,000	625
1: 1,000,000	250
1: 500,000	125
1: 250,000	63
1: 150,000	38
1: 125,000	31
1: 100,000	25
1: 63,360	16
1: 62,500	15
1: 50,000	13
1: 31,680	8
1: 30,000	7
1: 25,000	6
1: 24,000	6
1: 20,000	5
1: 15,840	4

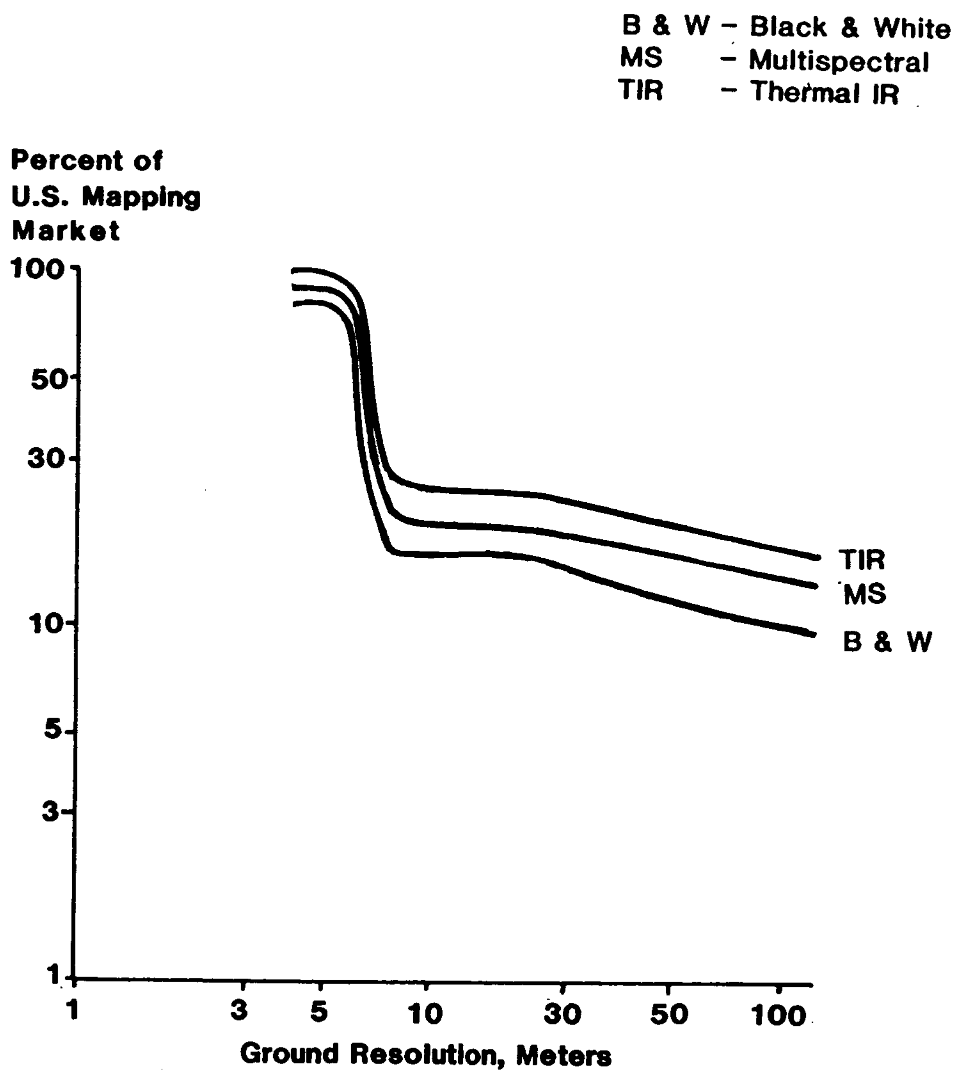

Figure 4-4. Addressable Market For Remote Earth Observations As A Function of Ground Resolution and Type of Imagery

Multispectral capability adds value to B&W imagery. As a minimum, if it can be provided at substantially the same price as B&W imagery, it strenghtens the "capturability" of the addressable market. For certain customers, multispectral imagery would command a somewhat higher price. However, the market is quite price sensitive. While most users prefer color, the higher current price limits the demand. The curve labeled "MS" in Figure 4-4 reflects our estimate of the additional market addressable by multispectral imagery as a function of resolution.[c] The curve labeled "TIR" shows the additional addressable market, if thermal infrared is added to the B&W and to the multispectral feature.

As regards the uniqueness parameter, space-derived imagery possesses several distinct advantages, demonstrated in practice by LANDSAT:

1. High geometric fidelity. RBV on LANDSAT 3 has shown geometric accuracy of order ±0.1% in the "raw" image. This compares with geometric distortions of several percent in aircraft photography. For precision work, alleviation of these aircraft distortions requires costly image rectification. Approximately 5% of aircraft imagery is currently rectified, at a cost of about $50 per image (1983 $).

   We estimate that the availability of RBV-type imagery with high geometric fidelity could expand total sales of remotely sensed products by approximately 4%.

2. High repetition rate. This feature is important to users who require observations spaced at frequent time intervals. Principal among these users are:

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[c] Op. Cit.

- Agricultural statistical services--desirable repetition is approximately ten days during the growing season. Remote sensing systems operating in the visible/IR spectrum need to repeat every three to five days to circumvent the masking effect of cloud cover. Estimated yearly U.S. market for these remote sensing products is approximately \$100,000-\$300,000.

- Geologic users--desirable repetition is four times per year, to allow observation of geological scenes under differing conditions of illumination, snowcover, humidity, etc.

- Disaster managers, e.g., floods--desired frequencies can be as high as every three days, to follow the progress of the phenomenon and associated damage-limiting activities.

  The ability of spaceborne remote sensing to provide high repetition rates can expand the market by approximately 5%.[d] We estimate that SAR imagery, which can achieve high repetition rates by virtue of its insensitivity to cloud cover, should also expand the market by another 5%.

Aggregating the features that are unique to space remote sensing, we estimate that a B&W spaceborne remote sensing system producing imagery at approximately 3 to 4 meter resolution could address approximately 90% of the U.S. mapping market if the total price of the data collection did not exceed 5% of the total costs. Addition of multipsectral and thermal imagery capabili-

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[d] Op. Cit.

ties would meet the lion's share of the market. The U.S. addressable market for "raw" remotely sensed products is estimated to be equivalent to $62 million/ year currently and $85 million/ year (in 1983 $) in 2000.

We estimate that the multiplying factor for the world market is approximately 3, thus establishing a world-wide addressable market of order $270 million (in 1983 $) by 2000.

The "capturable market," i.e., that share of the addressable which a future earth observation satellite could actually expect to "sell," depends to a large extent upon the competition among satellite systems, both domestic and foreign. The capturable market would be affected by national policies of price support and by potential future improvements in price/performance of airborne remote sensing systems. A reasonable estimate for a "very good" (high resolution, low price) system is half of the world market--$135 million per year. For an average (lesser resolution) system, we estimate the capturable market to be between one-tenth and one-fifth of the addressable market.

This bounds the allowable cost of the system, and sets the technological challenge--achievement of the requisite resolution-price, performance.

4.4.3 INTERPRETATION AND ELABORATION FUNCTION

Interpretation is the translation of features contained in the "raw" imagery into standard symbology and classifications, e.g., terrain topography, ground cover, urban habitats, waterbodies.

Elaboration, consisting of cartography and printing, converts interpreted data into finished map products. As shown in Table 4-9, it represents the largest share of current costs.

Whereas the data gathering function represents approximately 5% of the costs of civil mapping, Table 4-9, interpretation accounts for over 20%. Its addressable U.S. market is thus of order $250 million/year currently, $350 million/year (in 1983 $) in 2000. Worldwide, the year 2000 market could be as high as $750 to $1,000 million/year.

Two technologies are currently employed for interpretation:

- VS (Visual System)-based, also known as photointerpretation (PI). This technique has been used since the inception of aerophotography, circa 1910.

- Computer-based, also known as automatic classification. This technique was pioneered by NASA beginning in the late 1960s, specifically to interpret multispectral data gathered from aircraft and/or satellites.

VS-based systems are currently used to interpret the majority of remotely sensed data. Its accuracy is of order 90% for "normal" civil products, 95% and better for high quality products. Much effort has been expended, and is ongoing, (primarily on the part of DOD) to automate VS-based interpretation. Although progress has been encouraging, full automation is still a goal. DOD, for example, still employs approximately 4,500 photointerpreters.

Table 4-11 provides a calibration of the accuracy of automatic classification by computer-based systems using LANDSAT 1, 2, and 3 data. It shows that the automatic system has not yet reached the "utility" threshold. This may explain why LANDSAT market penetration has been limited. Somewhat improved results are anticipated from the higher-resolution LANDSAT Thematic Mapper Satellites.

TABLE 4-11

ACCURACY OF CLASSIFCATION FROM LANDSAT

(AVERAGE OF 224 TESTS, 10 GEOGRAPHIC LOCATIONS, ONE SIGMA CONFIDENCE)

	PROPORTION ESTIMATION[a]	**MAPPING**
ACCURACY, ALL CATEGORIES	74%	63%
ACCURACY, BY CATEGORY		
URBAN		30%
CROPLAND		55%
FORESTS		75%
WATER		86%
ACCURACY, THRESHOLD OF USER ACCEPTANCE	96%	85% TO 90%

[a] PROPORTION ESTIMATION IS THE MEASUREMENT OF THE TOTAL SURFACE COVERED BY A GIVEN SPECIES, e.g., WHEAT, WITHIN A CERTAIN REGION, e.g., HASKILL COUNTY, REGARDLESS OF WHFRE THE SPECIES IS LOCATED WITHIN THE REGION. PRIMARILY USED FOR CROP AND FOREST ACREAGE ESTIMATION. EASIER TO OBTAIN THAN MAPPING.

Achieving improved interpretation through automatic means **continues to be the technological driver** affecting the commercialization of Earth Resources Survey.

4.4.4 USER INFORMATION FUNCTION

This function converts the interpreted data into the final information products sought by the ultimate users. The conversion is performed by the final user or intermediate specialist (value-added industry) and occurs in two modes:

Mode 1. From map products augmented by auxiliary margin information--e.g., land use, topomaps, business activity censuses.

Mode 2. From raw or partially interpreted products such as annotated aerial photography combined with auxiliary information--e.g., combined use of aerophotos, aeromagnetic/gravitic surveys, geologic, seismic data by oil prospectors.

No comprehensive sizing of the dollars spent in performing the user information function has been developed. It is estimated to be on the order of several billion dollars per year in the U.S., the largest share accruing to Mode 2.[e]

The market for Mode 2 services for aircraft remote imagery is large. The corresponding market for services which exploit the unique characteristics (high geometric fidelity and repetitiveness) of space imagery is also large. If properly developed, it could overshadow the data gathering and the interpretation markets described above.

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e "Business Case for Remote Sensing Products," ECOsystems International, Inc., October 1979 for NASA Headquarters.

Key to addressing this market--indeed central to the long-term growth of Earth observation systems--is the development of technologies for economically accomplishing the user information function. Of these technologies, embracing pattern recognition, radiometric classification, multisensor and multidata correlation, the most challenging for long-term development is that of geometric pattern recognition. Section E.4 presents the state-of-the-art and projections for progress in this technology.

4.4.5 EARTH RESOURCES SURVEY FROM GEO

The dominant uniqueness feature of GEO-based observation systems is the opportunity of observing phenomena faster than from LEO systems, i.e., minutes to hours instead of days to weeks. This capability derives from the large field of view available from GEO. It further derives from the ability to exploit cloud dynamics, i.e., the fact that many cloud covers are not continuous but patchy and moving; thus ground objects obscured at certain moments can subsequently become revealed in relatively short time intervals.

To date, the value of this added uniqueness feature has not been reliably and credibly quantified. In our estimation, its principal application would be for warning of major meteorological disasters and consequent potential alleviation of their effects.

This application belongs to the functional mission category of Earth Atmosphere Observations, treated in Section D.2.

Two factors dominate the relevant opportunity cost parameter. First, achievement of requisite geometric resolution from GEO requires use of aperture diameters 40 to 50 times those needed from LEO. At optical wavelengths, a 10 meter diameter optical-precision aperture is needed to achieve the 4 meter resolution required for addressing the U.S. mapping market. The cost of fabricating and deploying such large structures within the time frame of this study appears to be incommensurate with their utility.

The second factor is that GEO observation systems are more limited in their area of coverage than LEO systems. A single GEO system could serve the Western Hemisphere, but three systems would be required to address the world market.

Our analysis indicates that GEO Earth Observation Systems capable of cost/effectively addressing the remote sensing market lie beyond the year 2010.

4.4.6 KEY TECHNOLOGIES

Table 4-12 summarizes the characteristics of a 2000-2010 era spaceborne remote sensing system that our analysis shows could effectively address the civil remote sensing market.

Based on projections of sensor and spacecraft technologies,[f] achieving the necessary spaceborne technological capabilities does not appear to be particularily difficult. The principal engineering challenge is to achieve these performance characteristics within the allowable cost windows.[g]

A related, more difficult challenge, is the development of improved interpretation and user information technology, as detailed in Volume IV, Section D.1, and in Volume V, Section E.4. Computer-based interpretation techniques, currently accurate to approximately 60-75%, could achieve the requisite higher perform

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f "NASA Space Systems Technology Model", NASA OAST, January 1984

g Another constraint could be institutional, relating to public dissemination of 3 to 4 meter resolution imagery.

TABLE 4-12

CHARACTERISTICS OF FUTURE
SPACEBORNE REMOTE SENSING SYSTEM

GROUND RESOLUTION	= 3 TO 5 METERS
AREA COVERAGE, YEARLY	
U.S.	= 2 TO 3 MILLION km^2
WORLD, U.S. INCLUDED	= 10 TO 20 MILLION km^2
LOCATION OF COVERAGE	= FOR MOST USERS, PREDESIGNATED AREAS
	= FOR A LIMITED NUMBER OF USERS, ADHOC AREAS: WITH REACT ON A QUICK REACTION CAPABILITY
REPETITION FREQUENCY	= FOR MOST USERS, APPROXIMATELY ONE TO THREE MONTH TIME BETWEEN TAKES
	= A LIMITED NUMBER OF USERS REQUIRE RE-IMAGING THE SAME SCENE AT 3 TO 5 DAY INTERVALS.
SENSING WAVELENGTH REGIONS	= PRIMARY: PANCHROMATIC (BLACK & WHITE) AND/OR SAR
	= SECONDARY: MULTISPECTRAL
	= TERTIARY: THERMAL IR
TOTAL ALLOWABLE YEARLY COST OF SPACE SYSTEM INCLUDING "RAW" PRODUCT GENERATION	= "AVERAGE" SYSTEM: $30 MILLION
	= "VERY GOOD" SYSTEM: $130 MILLION

ance (90 to 99%) if they could be made to operate on the geometric as well as the radiometric features of the data.

In summary, the technologies required to develop a remote sensing spacecraft and associated ground processing and distribution system that can compete with conventional methods are essentially available. The principal challenge is cost. The annual yearly operating costs for a **very good** system, including interest, amortization, O&M, and continuity R&D, should not exceed approximately $130 million (in 1983 $) in the year 2005-2010. The driving R&D challenge is automatic interpretation, combining geometric pattern recognition with multispectral radiometric analysis.

4.5 SUMMARY OF ANALYSES OF FUNCTIONAL SPACE MISSIONS

This section summarizes the findings of the analyses we conducted on all the functional space mission categories; the individual analyses are shown in Volume IV, Sections D.1 through D.9. The analyses show considerable variation among the missions with respect to their sensitivity to leapfrog improvements in effectiveness. Underlying all space missions is the need for technologies that reduce the cost of spaceflight.

The salient characteristics and key technology drivers of the missions, projected to 2005-2010, are recapitulated following.

Supporting Space Transportation

- **Structural efficiencies** currently being achieved--defined as the ratio of propellant weight to the weight of the entire lift-off vehicle, exclusive of payload--are **better than 90%.** For example, Delta's efficiency is 93%. Further increases in structural efficiency, such as may be possible though the use of advanced materials, portend only modest increases in the exchange ratio (kilograms at lauch per kilogram of payload deployed in space).

- Current costs of expendable launch vehicle structures range from $500 to $2000 per kilogram, in constrast with all-up costs of large commercial aircraft, which are of order $140/kg. Significant cost reduction should be sought not through use of improved structures --because their efficiency is already very high--but through application of **advanced manufacturing** techniques and use of new materials having low cost-to-weight ratios.

- Cost of launch services is as high as the cost of the launch vehicle itself. Cost reduction should be addressed: **automation of service functions** and use of innovative management techniques are avenues.

- Reducing launch vehicle structural costs by a factor of two combined with a 50% reduction of launch services costs appears to be reasonable goal. These actions alone would would lower the costs of space transportation by a factor of four; for a Delta, this would lower the cost per kiloram of payload in LEO from $10,000 to $2,500. Such improvements would place NASA heads and shoulders above any foreseeable foreign competition.

- Increasing propellant **specific impulses** is of major significance in decreasing the exchange ratio. Best fuels in current use (LOX-LOH) generate energies per unit weight (calories/kg) which are of order **one-fiftieth** (2%) that of the most energetic known chemical reactants. If these advanced propellants could be produced and exploited at costs comparable to those of current high-energy fuels (order of $0.08/kg), space transportation costs could be reduced by an order of magnitude, simply by virtue of the lighter structures that would be needed to orbit space payloads. The cost of these advanced propellants could be one to two orders of magnitude higher than LOX-LOH, without impacting significantly the cost of space transportation.

Earth Resources Survey

- Spacecraft and sensor technologies needed to achieve a remote sensing space system competitive with conventional airborne methods **are available now.**

- The principal requirement is low **cost.** Yearly recurring costs, including R&D amortization, for a "very good" space-based remote sensing system should not exceed $130 million (1983 $).

- The dominant utility parameter is **ground resolution**; 3 to 4 meter resolution at black & white would essentially satisfy the major portion of the imagery market.

- Addition of **multispectral** capabilities would add approximately 20% additional utility to B&W imagery, if provided at low cost.

- The driving technology issue is **automatic interpretation** of the remotely-sensed data, combining geometric pattern recognition with multispectral radiometric analysis.

Earth Atmosphere Observation

- The purpose of routinely observing the Earth's atmosphere is to improve the length and accuracy of **weather forecasts.** Three basic types of forecasts supporting important economic interests are in current use.

- Mesoscale forecasts, covering restricted geographic regions, aim at predicting the time of occurrence, location and intensity of local phenomena, such as tornadoes, severe winds, frosts.

- Synoptic forecasts, routinely provided by national weather agencies, cover large geographic areas, up to hemisphere. Their objective is to predict important atmospheric parameters such as pressure, temperature, rainfall.

- Climatological forecasts, covering geographic areas up to the entire globe and time spans ranging from weeks to years, aim at predicting long-term atmospheric trends, such as secular increases of temperature.

- Forecast accuracy has improved significantly over the last three decades as regards certain important atmospheric parameters, e.g., pressure, temperature, zone of expected arrival of hurricanes. For other parameters, e.g., rainfall, improvement has been slight.

- The consensus of the meteorological community is that significant forecast improvements can be brought about by increasing the density and frequency of data collection points. The only cost-effective means to accomplish this is via satellites. However, accuracy of measurement of key atmospheric parameters from satellites still lags by approximately an order of magnitude behind the precision achievable by conventional means, e.g., radiosondes. The mismatch is more severe for geosynchronous satellites. Notwithstanding, these offer the opportunity of continuous measurements as contrasted to LEO satellites, where recurrence of observation of the same area is only as frequent as twelve hours.

- Satellite limitations in accuracy, speed and areal resolution are not basic to sensor equipment. We know how to build sensors that are an order of magnitude more accurate than current versions. The limitation is the low level of energy that current satellite collectors can acquire.

- The driving technological issue related to the improved geometric, spectral and temporal resolution needed to achieve the high density of measurements required to improve forecasts is the capability to fabricate and deploy large energy-collecting structures. Typical diameters range from one meter in the optical range, to several meters in the thermal infrared, to several hundred, up to one thousand meters, in the microwave range.

Communications

- Communications traffic in the U.S. of all types--voice, video, data--accounts for approximately 45% of the world's traffic, and is doubling every 12 years.

- Domsats currently carry more than half of the world's satellite communications traffic. As a result, the geosynchronous arc over North America is becoming saturated.

- Saturation problems can be alleviated in the near-term by transitioning to higher carrier frequencies, such as the 30/20GHz band. By allowing narrower beamwidths and higher communications bandwidths, this technology could postpone saturation until approximately 2000.

- Higher frequencies, for example the 50/40GHz band, are being explored by USAF. However, attenuation by the atmosphere poses limits to very high frequencies.

- The driving technology need is the development of **large antenna** structures, with diameters of 50 meters and more, that can be deployed in GEO. In theory, this would allow multiple ground communications nodes to access the space antenna by virtue of space diversity. Achieving capability hinges on the development of manufacturing and deployment techniques that assure accuracy of antenna contour over large areas under varying space environmental conditions. The capability also requries the development of efficient means for on-board switching.

Navigation

- The object of space-based navigation systems is to supply terrestrial users--on land, sea, and air--with information that lets them know where they are, how fast and in which direction they are traveling.

- The Global Positioning System **(GPS)** provides this data worldwide, on call, within a few seconds, with accuracies ranging from 1 to 16 meters. Technically, GPS can serve the needs of navigational users well into the early 21st century. Widespread use of GPS capability, coupled with data processing technologies which are either available or which can be developed in the near-term, could provide the bulk of the U.S. population with facile means of traversing unknown surroundings. It could also provide for: a) control of airborne and maritime traffic; b) accurate survey of poorly known locations; c) continuous, accurate knowledge of the location of persons and/or vehicles with whom it is desired to maintain contact.

- The driving technology needed is reduction of the **cost** of GPS's terrestrial terminal equipment. Current costs are of order $5,000 to achieve 16 meter location accuracy, $50,000 for 1 meter. Reduction to the order of $200 and $2,000 respectively would open the era of mass use of space navigation.

- Design, mass production and marketing of inexpensive ground terminals is a function of private industry. NASA could provide the initial impulse.

- A potential role for U.S. government is the development of next-generation airline traffic control concepts and systems employing the capabilities of GPS.

Scientific Observations

- Our use of this term denotes only the purely scientific mission, as distinct from missions oriented to beneficial uses--e.g., Earth Resources Survey, Meteorology--or aimed at improving techniques of spaceflight--e.g., biomedical research, test of spacecraft subsystems.

- The key return from space science missions is information. The "value" of scientific data cannot be quantified objectively; much of it can bear unexpected fruits years and even decades hence. However, reduction of mission costs would enable more missions, producing more data per available dollar.

- For the average space science mission, **launch vehicles** account for approximately **20%** of the total cost; **launch services** for **20%**; the costs of the **instrumentation** represent **20%**; the costs of the **spacecraft** supporting the instruments (including structures, controls, on-board utilities, and data transmission) averages **30%**. Approximately **3%** of the total mission cost is devoted to the processing and analysis of the **scientific data,** including support of the scientific investigators.

- Comparison on an equal-performance basis of ground-based and airborne equipment with its spaceborne counterpart, shows that the costs of the latter are higher by two to three orders of magnitude. The high costs of the spaceborne instrumentation are attributed to the need for high reliability in the absence of periodic maintenance.

- Significant reductions of these costs are, in principle, possible within the environment of a manned space station. For ELVs, significant reductions are feasible by substituting multiple deployments of scientific instruments having lower reliability for single deployments of highly reliable equipment. This savings comes about because cost is an exponential function of reliability. Single equipment with very high reliability costs much more proportionally than multiple equipment of lesser reliability.

Extraction of Industrial Materials from the Moon

- Apollo and Lunachod have assayed specific sites of the upper lunar crust for presence and concentration of materials. The assays have shown an average composition not significantly different from the average composition of the Earth's crust. In particular, no economically-significant concentrations of specific materials have been found.

- Remote sensing of the lunar surface has likewise failed to indicate presence of economically-important concentrations of materials.

- Although they were widely dispersed over the Moon's visible hemisphere, the Apollo and Lunachod soundings were few in numbers. A similar limited number of dispersed assays on Earth could also have failed to reveal significant concentrations of ores. Thus an argument could be advanced in favor of possible economic findings, if only a denser assay were conducted.

- Countering this argument are general geological findings and theories. These indicate that the Moon, having been "frozen" in its present state approximately 4.5 billion years ago, has not enjoyed mechanisms conducive to mineral concentrations, such as tectonic plate motion, volcanic activity, hydrothermal phenomena. A possible exception could be offered by phenomena of magmatic separation, coupled with fissuring or other mechanisms venting enriched magma onto the surface.

- These findings indicate a high probability that average concentrations of lunar materials are of the same order as their average concentrations on Earth. On Earth, concentrations considerably higher than the average are needed for economically practical mining and extraction. As such exploitation of, lunar ores would require beneficiation, i.e., concentration by artificial methods.

- Development of economical benefication techniques would obviate the advantage of extracting materials from the Moon; because these techniques could be used far more economically on Earth. For example, the Matterhorn contains, in diluted form, a mass of iron equivalent to 20 years of U.S. iron production. It does not therefore appear that the Moon constitutes an economical source of industrial materials for return to, and use on Earth.

- There is however sufficient residual uncertainty in this finding (estimated at 10-15%) as to warrant consideration of the following actions by NASA: a) further in-depth scientific investigation of potential lunar mechanisms which could have induced concentrations of minerals; b) modest, low cost, program of further remote and in situ exploration of the Moon for the purpose of seeking ore concentrations.

- Various proposals have been advanced for use of lunar materials to build LEO and GEO infrastructures. While lunar escape velocities are much lower than Earth's, thus in theory launch costs form the Moon would be lower than from Earth, the investment required to establish lunar mineral extraction facilities is very high. From a strictly utilitarian standpoint, this particular usage of lunar materials appears to lie beyond the time frame of this Study.

Extraction of Useful Materials From the Asteroids

- From the utilitarian standpoint, the arguments advanced on the subject of lunar materials hold "a fortiori" for asteroidal materials. In fact, analysis of meteorite falls and findings on Earth indicate that approximately 6% of the asteroids appear to contain high concentrations of important materials such as iron and/or nickel. However, at the present state-of-the-art, the round trip from and to Earth would last several years; the transportation costs would exceed by far the value of any known material which would be eventually returned to earth.

- The economics of this space mission place it well beyond the time frame of this Study. The key to its future accomplishment is significant reduction in space transportation costs.

Exploitation of the Solar System as a Human Habitat

- Expansion of human colonies onto the Moon and Planets has been suggested for the purpose of relieving the population pressure on Earth, or in pursuit of other utilitarian aims, e.g., mining and return to Earth of economically useful materials.

- As regards utilitarian aims, the economic exploitation of lunar, asteroidal and planetary material has been discussed in the previous paragraphs. Its fruition lies clearly beyond the time frame of this Study.

- As regards the use of planetary bodies as human habitats, the environmental conditions discovered thus far to prevail on planetary bodies within the solar system are adverse, with the possible exception of some Jovian satellites. The costs of adapting these environments to human habitation, coupled with the costs of space transportation, place this possibility well beyond the time frame of this Study.

Generation of Energy for Use on Earth

- Solar power satellites (SPS) have been proposed as sources of space-generated energy for use on Earth. For obvious engineering reasons, a practical SPS must be placed in GEO.

- Current costs of coal-fired electric energy are of order $0.02/kWh. Of this, $0.0075 to $0.01 is attributable to fuel, the remainer to amortization of the central generating plant. (The current industrial sales price of electric energy, of order $0.06 to $0.08/kWh, includes the amortization of the distribution network. Such amortization would equally apply to

SPS-generated energy). Except for inflation, these costs are not expected to rise significantly in the future, because of the ample availability of coal in the U.S.

- SPS development scenario consisting of deployment of a 1MW prototype (approximately 10,000m^2 collector area) in 1994 followed by deployment of an industrially-scaled facility between 10MW and 1GW ten years later (2004).

- Our computations show that the postulated family of SPS could deliver electric energy at an Earth-based power central at the following unit costs:

	1994	2004
1MW PROTOTYPE	$13.33/kWh	$4.24/kWh
10MW INDUSTRIAL SCALE	--	$2.34/kWh
100MW INDUSTRIAL SCALE	--	$1.34/kWh

- The capital investments, in millions of 1983 dollars, required to implement industrial SPS systems, circa 2004, would be as follows:

SYSTEM	HARDWARE	TRANSPORTATION
10MW	$1,010M	$42M
100MW	$5,818M	$237M
1GW	$32,720M	$1333M

- The above shows that the key to a competitive photovoltaic SPS is reduction of solar collector costs and weights. To compete with coal-fired electric energy costs of $0.02/kWh, the cost of space-hardened solar cells would have to reduce to approximately one-one hundredth of its current level. If this were to be realized within the next 20 years, the costs would have to undergo a yearly compound decrement of 0.8 in contrast to the 0.95 yearly decrement currently being experienced. Should the current rate of technological progress be maintained, the era of practical realization of a photovoltaic SPS would begin about 2040-2050.

- The foregoing indicates that, assuming that technology will continue to evolve at the current pace, practical realization of a photovoltaic SPS lies beyond the time frame of this Study.

CHAPTER 5
TECHNOLOGY THRUSTS ADDRESSING COMMON REQUIREMENTS

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5.0 TECHNOLOGY THRUSTS ADDRESSING COMMON REQUIREMENTS

This Chapter considers the feasibility of implementing new technology thrusts that address the technological, long-term needs common to industry and NASA. It assesses the degree of commonality that exists between the identified "pervasive" technologies portending major advances in industrial productivity and social well-being and the technologies that underlie bold advances in the nation's space capability. It presents viewpoints of selected government personnel involved with technology policy, regarding the concept of establishing coordinated, government-industry programs; and it sets forth a framework for planning program implementation.

5.1 COMMONALITY AMONG TECHNOLOGIES

Table 5-1 lists the ten long-term pervasive technologies associated with the industrial sectors and social aspirations that we analyzed. Each pervasive technology addresses common requirements underlying major productivity improvements, not restricted to any one industry but effective across the board. The table also lists the long-term technologies that provide the basis for conducting advanced space missions.

We assessed the degree to which the industry-oriented technologies could benefit from inherent NASA capabilities, and the degree to which their development contributes to the space program. As shown in Figure 5-1, our assessment indicates that NASA's capability to stimulate advances extends to all the pervasive technologies because NASA has in-house relevant talents and demonstrated capability to organize and manage external industrial and academic capabilities. Regarding the impact of the pervasive technologies on the space program, we identify four levels of contribution:

TABLE 5-1

DRIVING TECHNOLOGY REQUIREMENTS: 2010 HORIZON

U.S. INDUSTRY	CIVIL SPACE
• HYPERSTRENGTH MATERIALS	• ADVANCED PROPULSION
• MULTIPROPERTY MATERIALS	• REMOTELY-SENSED IMAGE INTERPRETATION
• MOBILE ENERGY	• LARGE ORBITING APERTURES
• ARTIFICIAL INTELLIGENCE	• INTERACTIVE DATABASES
• INFORMATION RATIONALIZATION	• DIFFUSABLE TERMINALS
• ACCELERATED LEARNING	• INEXPENSIVE SPACE TRANSPORTATION - LOW COST VEHICLES - COST/EFFECTIVE LAUNCH AND MISSION OPERATIONS
• LIVE-PRESENCE COMMUNICATION	
• PATTERN RECOGNITION	
• BIOTECHNOLOGY	
• MEDICAL ENGINEERING	

NASA CENTERS / PERVASIVE TECHNOLOGIES	LaRC	GSFC	LeRC	ISC	MSFC	IPL	ARC
HYPERSTRENGTH/ MATERIALS	●						
MULTIPROPERTY MATERIALS			●				
MOBILE ENERGY			●				
ARTIFICIAL INTELLIGENCE				●		x	
INFORMATION RATIONALIZATION					●		
ACCELERATED LEARNING					x		
LIVE-PRESENCE COMMUNICATION			x		x	x	
PATTERN RECOGNITION		x				●	x
BIOTECHNOLOGY				x		●	
MEDICAL ENGINEERING			x	x		●	

● SIGNIFICANT-INCLUDING PAST OR ONGOING PROGRAMS
x POTENTIAL

Figure 5-1. Principal NASA Centers with Expertise in Pervasive Technologies

- Advances in **Artificial Intelligence, Information Rationalization, Pattern Recognition** have a **direct** impact upon the space program. These technologies underlie advances needed to achieve powerful interactive databases that better utilize scientific space data. They also are key to advances in remotely-sensed image interpretation. And they provide the underpinnings for a more capable space station and for planetary surveys, leading to eventual missions aimed at establishing human habitats within the solar system.

- Developments in **Hyperstrength** and **Multiproperty Materials directly** support NASA's objectives in aeronautics. To a lesser degree, they enhance specialized facets of the space program, such as Large Orbiting Apertures and Low Cost Vehicles for space transportation.

- Advances in **Mobile Energy** would not only provide a strong R&D impetus to industry, but would **support** future space requirements for orbital energy storage. Advances in **Live Presence Communications** and **Biotechnology** also **support** space objectives: The technology needed for civil telecommuting **supports** space teleoperators; **Biotechnology** and **Medical Engineering** developments **support** a spectrum of space requirements such as advanced life support systems needed for planetary habitats.

- Progress in **Accelerated Learning,** a key ingredient to improving industrial productivity, would **tangentially** benefit the space program by enabling improvements in productivity throughout the aerospace industry; e.g., lower cost launch operations through rapid training of launch and space crew personnel.

Our assessment showed only limited coupling of the ten pervasive industrial technologies with the space-oriented requirements of Advanced Propulsion and Diffusable Terminals.

Figure 5-2 shows the interdependencies between the pervasive industry-oriented technologies and the driving space technologies.

These varying degrees to which industry-oriented technology developments contribute to the space program represent a dominant factor to be considered in structuring a NASA long-term, industry-supportive technology thrust program. Industry-oriented technologies that directly couple with space requirements would be primary candidates. They provide the high leverage opportunities with the broadest payoff. However, as described in Sections 5.2 and 5.3, other considerations also have to be examined in selecting R&D thrusts that go beyond the space program itself.

5.2 VIEWPOINTS ON COORDINATED GOVERNMENT-INDUSTRY TECHNOLOGY THRUSTS

Institutional considerations play a major role in structuring technology programs in which government participates with U.S. industry in addressing common technology goals. Although such programs have precedents--USDA's County Agent system and NACA are prime examples--their number is limited, and, in recent years, their acceptance has been debated. To obtain guidance with respect to institutional acceptance of the programs envisioned in this study, we sounded out the views of technology policy personnel in relevant government agencies. We presented study findings to the organizations shown in Table 5-2.

The overall reaction was favorable. Most reviewers indicated that the concept of NASA attempting to stimulate long-term basic technological innovations aimed at improving industrial productivity was in consonance with Administration policy; and

	ADVANCED PROPULSION	REMOTE IMAGE INTERPRETATION	LARGE ORBITING APERTURES	INTERACTIVE DATABASES	DIFFUSABLE TERMINALS	INEXPENSIVE SPACE TRANSPORTATION	
						LOW COST VEHICLES (LAUNCH & ORBITAL)	COST/EFFECTIVE LAUNCH/MILLION OPS
HYPERSTRENGTH MATERIALS			○				
MULTIPROPERTY MATERIALS	•		•		○	•	
MOBILE ENERGY							
ARTIFICIAL INTELLIGENCE		○					
INFORMATION RATIONALIZATION				●			
ACCELERATED LEARNING	X	X	X	X	X	X	○
LIVE-PRESENCE COMMUNICATION			•			○	
PATTERN RECOGNITION		●		○			
BIOTECHNOLOGY						•	
MEDICAL ENGINEERING						•	○

IMPACT OF PERVASIVE TECHNOLOGY
● DIRECT
○ ENHANCING
• SUPPORTING
X TANGENTIAL

Figure 5-2. Commonality Among Pervasive Industry-Oriented and Space-Enabling Technologies

TABLE 5-2

BRIEFINGS CONDUCTED ON NEW TECHNOLOGY THRUST PROGRAMS

- **CONGRESS**
  - -- SENATE SUBCOMMITTEE ON SCIENCE, TECHNOLOGY AND SPACE
  - -- HOUSE SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATION
  - -- SENATE APPROPRIATIONS COMMITTEE
  - -- HOUSE APPROPRIATIONS COMMITTEE
- **EXECUTIVE**
  - -- OFFICE OF SCIENCE AND TECHNOLOGY POLICY
  - -- OFFICE OF MANAGEMENT AND BUDGET
  - -- OFFICE OF TECHNOLOGY ASSESSMENT
  - -- NASA ADVISORY COUNCIL
  - -- NATIONAL RESEARCH COUNCIL
  - -- DEPARTMENT OF COMMERCE
  - -- FEDERAL AVIATION ADMINISTRATION
  - -- NASA ASSOCIATE ADMINISTRATORS
- **INDUSTRY**
  - -- FORD MOTOR COMPANY
  - -- GENERAL MOTORS
  - -- THE BOEING COMPANY

would likely receive broad support in Congress. We found near-total consensus that NASA should initiate such a program; however, one group--the NASA Advisory Council--questioned the advisability of NASA undertaking a research program not directly supporting space. The presentations elicited viewpoints and concerns that need to be considered in planning program implementation.

The "positive" comments included:

- "The approach would be supportive of other ongoing efforts--government and private--to revitalize the U.S. position in the world marketplace, particularly in the high technology arena."

- "Government agencies should be assuming more active roles in stimulating technologies. Government should support such efforts, at least to the point of proof-of-concept. Industry should be brought into such efforts as early as possible and encouraged to take over as soon as developments appear practical."

- "Technology development programs undertaken by government agencies should focus on long-term requirements and not compete with short-term industrial programs."

- "New efforts NASA may undertake should not fall into a trap experienced in the past, in which a solution was developed first and then a search undertaken for a customer. Every effort should be made at identifying and understanding customer needs right from the beginning."

- "NASA technology development should be concentrated on basic problems."

- "NASA needs to recognize that several federal agencies are already moving in directions envisioned in the Study." Among these are the Department of Commerce and the National Institutes of Health.

- "NASA should not overlook the fact that a major source of potential technology is the Department of Defense. To the extent that DOD's efforts support pervasive technologies, means should be devised to integrate unclassified results into the NASA technology thrust programs."

- "Several government agencies have capabilities in advanced technologies; but NASA is the logical organization to lead the mission."

Certain reviewers expressed reservations:

- "Attempts by NASA to become involved with industry-oriented research would tend to dilute concentration on the more ambitious aspects of space exploration, such as manned Mars, exploration of the outer planets..."

- "The number one objective of this Office (White House Science Office) is upgrading the level and quality of basic scientific and technical education. Any developments in this area would be highly regarded."

- The space science community, particularly in astronomy, is concerned that too high a percentage of space science funding goes to "tin bending." Some scientists might regard industry-oriented programs as further diverting support from scientific endeavors. However, they would support the Study's finding that a principal NASA objective ought to be development of advanced technologies that increase the cost/effectiveness of space scientific data gathering.

5.3 PLANNING TECHNOLOGY THRUST PROGRAMS

We see the following five steps as constituting an effective framework for planning "new technology" mechanisms:

Step 1. Understand the concerns and reservations of the key policy-making agencies regarding the new technology thrusts; and assess the disposition of relevant agencies to assist in such efforts.

Step 2. Similarly, understand the reservations and willingness of relevant industrial groups to participate in such efforts.

Step 3. Assess the merits of alternative mechanisms for implementing new technology thrusts, including a review of experience and lessons-learned in establishing similar programs in the U.S. and abroad, in particular, in Japan and France.

Step 4. Combine the findings of Steps 1, 2, and 3 with the technical and economic requirements to select representative new technology thrusts to serve as pilot efforts.

Step 5. For each pilot effort, develop a program plan including:

- Suggested NASA and industry participants,
- Realistic milestones,
- Suggested organizational structures,
- Recommended program budgets.

In subsequent phases of the Study, we plan to extend our initial sounding of the views and concerns of government agencies (Step 1) and to carry out planning Steps 2 through 5.

Several key factors affecting this planning have emerged in the course of the Study:

- Recognizing the long-term horizon of the pervasive technologies (2005-2010), meaningful intermediate milestones need to be established. These must provide industry with periodic useful results, to "justify" the program and evoke continuing support. To sustain a long-term program, periodic measures of progress ("return on investment") need to be established.

- The challenges presented by the pervasive technologies require the talents of the most capable scientists and engineers. Many can be drawn from within the relevant NASA Centers; the requisite extramural talent can be marshalled through NASA's established technical and contract management systems.

- The structure of new technology thrust programs must conform with established NASA "culture." Support from highest executive levels will serve to motivate and assure assignment of top technical and managerial "space people."

- Similarly, provisions need to be made to encourage participation of outstanding government personnel from outside NASA. Some agencies are already considering similar industry-related activities, e.g., the Office of Productivity, Technology and Innovation in the Department of Commerce and the SDIO in DOD. Concrete coordination among these efforts will simplify industry's interfacing, i.e., minimize "red tape."

- Four "model" government-industry structures have been used or proposed for related types of programs.

1. **In-house programs**--wholly funded and managed by a single agency employing internal and contracted resources.

2. **Inter-Agency programs**--with funding and management responsibilities shared in accordance with Inter-Agency Agreements.

3. **Centers of Excellence**--with funding shared in various degrees by government, industry and academia; management responsibility is sometimes held by government, frequently contracted to academia.

4. **Government-industry limited partnerships**--this is the newest model, proposed by the Department of Commerce and being explored by NASA to foster the commercial uses of space.

Each of these models could be employed for the NASA technology thrust programs examined by this Study. Their merits and limitations need to be assessed, not in general, but with regard to the characteristics of each specific technology and of its industrial constituency.